PROCUREMENT, COST OVERRUNS AND SEVERANCE: A STUDY IN COMMITMENT AND RENEGOTIATION

by

JEAN TIROLE

TECHNICAL REPORT NO. 455
December 1984

A REPORT OF THE
CENTER FOR RESEARCH ON ORGANIZATIONAL EFFICIENCY
STANFORD UNIVERSITY
Contract ONR-N00014-79-C-0685, United States Office of Naval Research

THE ECONOMICS SERIES

INSTITUTE FOR MATHEMATICAL STUDIES IN THE SOCIAL SCIENCES
FOURTH FLOOR, ENCINA HALL
STANFORD UNIVERSITY
STANFORD, CALIFORNIA

--- 1 OF 1

--- 1 - AD NUMBER: A151546
--- 2 - FIELDS AND GROUPS: 5/1, 12/1, 15/5
--- 5 - CORPORATE AUTHOR: STANFORD UNIV CA INST FOR MATHEMATICAL STUDIES
--- IN THE SOCIAL SCIENCES
--- 6 - UNCLASSIFIED TITLE: PROCUREMENT, COST OVERRUNS AND SEVERANCE. A
--- STUDY IN COMMITMENT AND RENEGOTIATION.
--- 9 - DESCRIPTIVE NOTE: TECHNICAL REPT.,
---10 - PERSONAL AUTHORS: TIROLE,J. ;
---11 - REPORT DATE: DEC , 1984
---12 - PAGINATION: 67P HC COST: $ 5.00
---14 - REPORT NUMBER: TR-455
---15 - CONTRACT NUMBER: N00014-79-C-0685
---20 - REPORT CLASSIFICATION: UNCLASSIFIED
---33 - LIMITATION CODES: 1

PROCUREMENT, COST OVERRUNS AND SEVERANCE: A STUDY IN COMMITMENT AND RENEGOTIATION

by

JEAN TIROLE

Technical Report No. 455

December 1984

A REPORT OF THE
CENTER FOR RESEARCH ON ORGANIZATIONAL EFFICIENCY
STANFORD UNIVERSITY

Contract ONR-N00014-79-C-0685, United States Office of Naval Research

THE ECONOMICS SERIES

INSTITUTE FOR MATHEMATICAL STUDIES IN THE SOCIAL SCIENCES
Fourth Floor, Encina Hall
Stanford University
Stanford, California
94305

PROCUREMENT, COST OVERRUNS AND SEVERANCE: A STUDY IN COMMITMENT AND RENEGOTIATION*

by

Jean Tirole**

1. Introduction

Procurement is widely used by government agencies and private firms to perform their research, development and production projects. o some extent procurement can be considered a rule as even in-house projects involve a decentralization of responsibility to a research or a production department. The purpose of this paper is to analyze decision-theoretic and incentive aspects of procurement procedures.

The first fundamental feature of R&D and risky production projects is the sequential nature of information, tasks and decisions. Over time information is obtained about the cost and the value of a project (where the value can reflect demand conditions or the development of substitutes). Accordingly optimal decisions about investment, implementation or severance (or more generally the level of activity) are contingent on the current state of knowledge. A vast Operations Research literature has developed in the late fifties and early sixties on the

---

*This work was supported in part by Office of Naval Research Grant ONR-N00014-79-C-0685 at the Institute for Mathematical Studies in the Social Sciences, Stanford University, and in part by the Commissariat au Plan (French Planning board) contract on Government contracts at C.E.R.A.S. The author is grateful to Ken Arrow, David Besanko, Vince Crawford, Oliver Hart, Eric Maskin and Bob Wilson for helpful discussions and comments. After this work was completed, the author was informed of the earlier work by Pratt and Zeckhauser [1982], who also generalize the d'Aspremont-Gerard Varet result to dynamics. Proposition 4 (implementation of the first best under commitment) can be regarded as a special case of their result.

**Massachusetts Institute of Technology.

decision-theoretic aspects of sequential projects.[1/] More recently this literature has been revived by more economically oriented papers.[2/]

The second fundamental aspect is that the project usually is not carried out by the sponsor, as suggested by the word "procurement." In a first approximation the situation can be described as a traditional principal-agent relationship.[3/] The departure from a single decision-maker analysis is justified by the asymmetry of information between the two parties. Typically the sponsor has more information about the value of the project while the R&D or production unit has superior information about the cost and/or the investment it makes in the relationship.

This paper aims at integrating these two aspects and literatures. It departs from the traditional principal-agent tradition in that the sequential nature of information and decision implies an exchange of information and joint-decision making at each stage of the process. It differs from the decision-theoretic models because it recognizes that asymmetric information raises the possibility of "opportunism." The achievements of this paper are very modest compared with its goal; accordingly this work can only be considered as a first step toward more general and more sophisticated models.

The basic model (Section 2) is that of a firm engaged in an R&D process. This firm aims at reducing the cost of manufacturing a given good and to produce it at an optimal date, if it produces it at all. Over time information accrues about the value of the project and the cost of its final implementation. At the beginning of each period, three options are available: 1) stop the project; 2) implement the project, i.e., produce at the current cost estimate; 3) do some more R&D. If the third option is picked, the firm invests in R&D activity.

It then obtains a new cost estimate. Meanwhile the sponsor also gets more information about the value of the project. At the beginning of the following period the same three options are available; and so on. Section 3 characterizes the optimal decison-theoretic process ("first-best policy"), i.e., the solution that would obtain under symmetric information.

Section 4 considers a two-party relationship (sponsor/firm) and states the informational restrictions that are assumed in (most of) the rest of the paper. It is argued that these assumptions may be satisfied in a number of interesting R&D procurement situations.

Section 5 studies the ideal case in which both the sponsor and the firm are able to commit themselves to given information exchange, decision-making and transfer procedures. There it is shown that, in spite of bilateral asymmetric information and moral hazard, if the parties are risk neutral, the first best policy is implementable by a suitably chosen sequential mechanism. The latter generalizes the Arrow [1979]-d'Aspremont-Gerard Varet [1979]-Groves-type mechanism to dynamic situations. In particular the effect of current exchanges of information on future ones is corrected in order for the parties to reveal their information truthfully.

However full commitment is fairly unlikely, as argued in Section 6 which states the main reasons (bankruptcy, cancellation, design changes, transaction costs). As commitment is restricted in most procurement situations, one must consider the issue of sequential renegotiation. Renegotiation is generally characterized by the presence of ex-post individual rationality constraints, which affect the set of possible allocations. Section 7 uses a two-period version of the general model to study this issue. It is assumed that the sponsor and the firm bargain over implementation and transfer in the second period. It is shown that, if the sponsor cannot observe specific investment, in the absence of commitment the firm invests too little in the relationship. This result tends to confirm Williamson's [1975] ideas about opportunism and suboptimal investment in specific assets. Section 7 also shows that if the sponsor could observe specific investment, the latter would tend to exceed that under unobservability, and could even exceed its first best level.

Section 8 considers the role of cancellation fees in renegotiation situations. These have been long advocated by the Department of Defense in the U.S. for military procurement.[4/] Formally cancellation fees can be seen as reintroducing some commitment from the sponsor's point of view; also they are very similar to Williamson's [1983] hostages. It is shown that cancellation fees can well decrease the firm's investment in the relationship, contrary to what is usually argued.

Lastly Section 9 offers a few thoughts about the so-called "cost overruns" while Section 10 discusses related work.

The examples given to motivate the set-up (in particular the informational assumptions and the degree of commitment) are mostly taken from military procurement situations, on which there is abundant evidence. A number of features are certainly also relevant to other procurement procedures.

2. The Model

The sponsor wants to develop a new product. Time is discrete: $t = 1,\dots,T$. At time t, c_t denotes the expected cost of implementing the project. In other words if production starts at time t, the expected total cost of production discounted at t is $c_t > 0$. One can envision the production of a fixed number of units of the product. The model could easily be generalized to include the choice of a production level. Let v_t denote the expected (monetary) value of the project discounted at t. As suggested by the notation, I will assume that risk-neutrality holds (except in Section 8).

At time t, c_t and v_t are known. Three options are then available:

(S) stop the project

(I) implement, i.e., produce

(R) continue R&D.

If S (respectively I) is chosen, the gain (gross of sunk costs) is zero (respectively $(v_t - c_t)$).

If R is chosen, some R&D investment (effort) level $e_t \geq \underline{e} > 0$ is picked (at cost e_t). $\underline{e}$ can be interpreted as a fixed cost of investment.[5] Next period's expected cost becomes

$$c_{t+1} = C_{t+1}(c_t, e_t, \theta_t) \quad ,$$

where θ_t is some exogenous random variable with continuous distribution on $[0,1]$. The random variable is independent of history up to time t. For notational simplicity I will often suppress it and simply write

$$c_{t+1} = \tilde{C}_{t+1}(c_t, e_t) \quad .$$

The sponsor also learns about the value of the project between t and $(t+1)$, i.e.,

$$v_{t+1} = V_{t+1}(v_t, \eta_t) \quad ,$$

where η_t is some exogenous random variable with continuous distribution on $[0,1]$. η_t is independent of history up to time t and of θ_t. Similarly I will sometimes use the notation:

$$v_{t+1} = \tilde{V}_{t+1}(v_t) \quad .$$

Let $\gamma \varepsilon (0,1)$ denote the discount factor. The initial levels of expected value and costs are v_1 and c_1. The object of the problem is to define a <u>sequential decision rule</u> $\delta_t(v_t, c_t) \varepsilon \{S, I, R\}$ and a <u>conditional investment program</u> $e_t(v_t, c_t)$ so as to maximize

$$W_1(v_1, c_1) = E[\sum_{t=1}^{T} \gamma^t((v_t - c_t)1_{\{I_t\}} - e_t 1_{\{R_t\}})] \quad ,$$

where I_t denotes the event $\{\delta_1(v_1, c_1) = \ldots = \delta_{t-1}(v_{t-1}, c_{t-1}) = R$ and $\delta_t(v_t, c_t) = I\}$, R_t denotes the event $\{\delta_1(v_1, c_1) = \ldots = \delta_t(v_t, c_t) = R\}$ and 1 denotes the characteristic function. The expectation is taken with respect to the relevant random variables.

Let us now state the assumptions:

Assumption 1: C_{t+1} and V_{t+1} are continuously differentiable .

Assumption 2: $\frac{\partial C_{t+1}}{\partial e_t} < 0$ and $\lim_{e_t \to \underline{e}} \frac{\partial C_{t+1}}{\partial e_t} = -\infty$.

Assumption 3: $0 \leqslant \frac{\partial C_{t+1}}{\partial c_t} \leqslant 1$ and $0 \leqslant \frac{\partial V_{t+1}}{\partial v_t} \leqslant 1$.

Assumption 4: $\frac{\partial C_{t+1}}{\partial \theta_t} > 0$, $\frac{\partial V_{t+1}}{\partial n_t} > 0$.

Assumption 2 says that investment reduces the production cost. Furthermore the marginal productivity of investment is infinite at the minimum level of investment. This is just to make sure that an interior solution prevails if R is chosen.

Assumption 3 first says that costs and values are positively correlated over time. A high cost today is likely to lead to a high cost tomorrow; and similarly for the values. The second part of Assumption 2--that cost and value estimates at $(t+1)$ do not increase faster than their estimates at t--deserves more justification. The assumption $\frac{\partial C_{t+1}}{\partial c_t} \leqslant 1$ says that for a given investment level cost reduction is more intense at higher costs than at lower costs. The assumption $\frac{\partial V_{t+1}}{\partial v_t} \leqslant 1$ is natural as Bayesian updating usually gives a sensitivity to the earlier estimate smaller than one.[6]

3. Characterization of the First Best Policy

In this Section I assume that the sponsor and the firm have identical information (v_t, c_t) at each date t and that the sponsor observes the firm's investment. They will be formalized as a single decision-maker.

At time t, the decision-maker maximizes the expected present discounted value of "profits" (gross of sunk costs) $W_t(v_t, c_t)$. W_t satisfies the following recursive equation

$$(3.1) \qquad W_t(v_t, c_t) = \max\{0;\ v_t - c_t;\ W_t^R(v_t, c_t)\}$$

where

$$(3.2) \qquad W_t^R(v_t, c_t) = \max_{e_t \geq \underline{e}} \{Z_t^R(v_t, c_t, e_t)\}$$

and

$$(3.3) \qquad Z_t^R(v_t, c_t, e_t) = -e_t + E(\gamma W_{t+1}(\tilde{V}_{t+1}(v_t), \tilde{C}_{t+1}(c_t, e_t))) \quad .$$

The three terms in the right-hand-side of (3.1) correspond to the three possible choices $\{S;\ I;\ R\}$. W_t^R is the value when decision R is chosen. The boundary condition is

$$(3.4) \qquad W_T(v_T, c_T) = \max\{0;\ v_T - c_T\} \quad .$$

I now make an assumption that ensures the existence of a unique optimal level of investment if decision R is picked:

Assumption 5: For all (t,v_t,c_t), $Z_t^R(v_t,c_t,e_t)$ is strictly quasi-concave in e_t.

I now give properties of the first best policy which will be used in subsequent proofs. The proofs of propositions 1 to 3 are given in Appendix I. Let $\{\delta_t^*,e_t^*\}$ denote the optimal policy. Under Assumptions 1 through 5 we have:

Proposition 1: If $\delta_t^*(v,c) = S$, $v' \leqslant v$ and $c' \geqslant c$, then $\delta_t^*(v',c') = S$.

Proposition 2: If $\delta_t^*(v,c) = I$, $v' \geqslant v$ and $c' \leqslant c$, then $\delta_t^*(v',c') = I$.

Proposition 3: The level of investment e_t^* grows with the current value v_t.

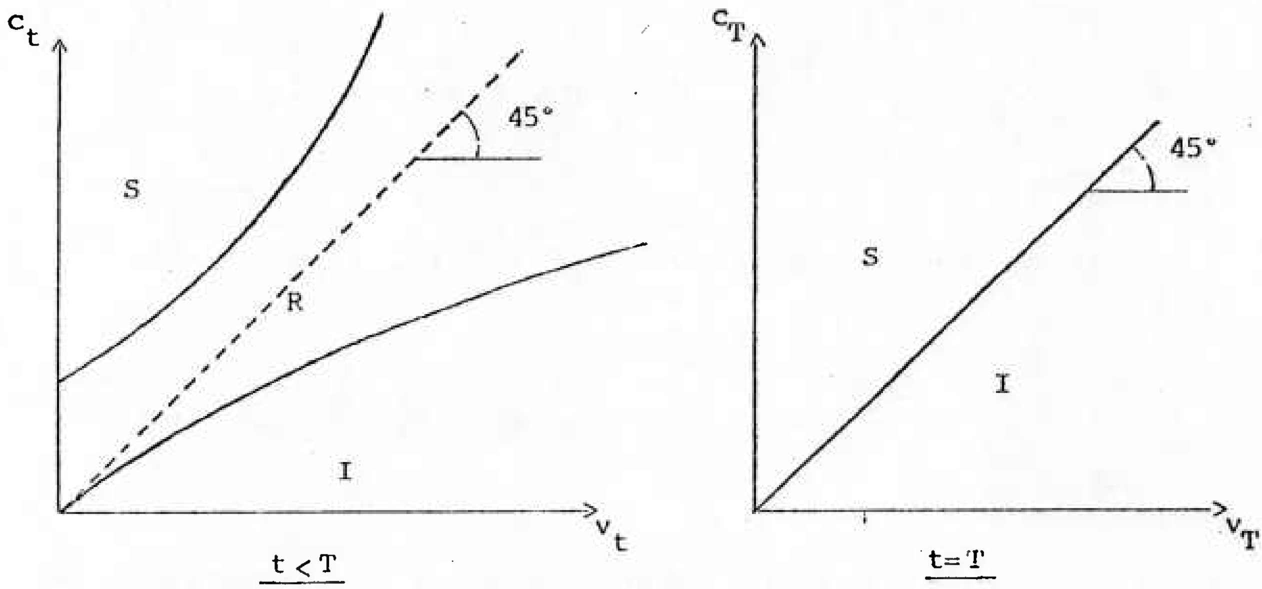
Propositions 1 and 2 are fairly intuitive: if the decision-maker decides to cancel the project $(\delta_t^*(v_t,c_t) = S)$ for some levels of cost and value, it will do so a fortiori if the cost increases and the value decreases. And conversely for implementation. These two propositions imply that δ_t can typically be represented by Figure 1.

Proposition 3, which is relevant only if $\delta_t^*(v_t,c_t) = R$, says that a higher current estimate of the value of the project induces a higher investment. The intuition behind it is that a high current value increases the probability of future implementation, and hence increases the profitability of current investment.

4. Informational Assumptions

I now describe the sponsor and the firm as two separate parties having private information and acting strategically. I will assume that:

Figure 1



(There are at most three regions in the $\{v_t, c_t\}$ plane. Depending on the technology, some of these regions may not exist).

Assumption 6: The sponsor and the firm have the same information (v_1, c_1) at the start. All probability distributions are common knowledge.

Assumption 7: The sponsor observes v_t, but not c_t and e_t (except for c_1). Neither does it observe the (ex-post) realization of the cost in case of implementation. The firm observes c_t and chooses e_t, but does not observe v_t (except for v_1).

Assumption 6 first states that the two parties start with symmetric information. This assumption rules out adverse selection at the initial (contracting) date. This is not to say that adverse selection problems in procurement are not important; they certainly are (see, e.g., Scherer [1964], p. 227). There is an extensive literature on procurement under adverse selection about the firm.[7] However when the sponsor has private information as well, as is the case here, matters become intricate because the mechanism is "designed by an informed principal" (Myerson [1983], Crawford [1983a]). Ruling out initial adverse selection avoids such intricacies without much loss as I want to focus on the dynamic aspects of procurement.

The assumption that all probability distributions are common knowledge is very strong, but is hard to do without. A more satisfactory approach would be to use dominant strategy mechanisms. These however are difficult to characterize; furthermore the class of dominant strategy mechanisms is likely to be small so that choosing a contract in that class may entail a high welfare loss.

Let us now discuss Assumption 7. First I assume that the sponsor observes the expected value of the project, but that the firm does not. This is a natural assumption as the sponsor usually is or works for the final user. The firm in general lacks information about value. One reason is that the value can be subjective. Also even if it somehow is objective, the sponsor is usually endowed with superior information.

For example the Department of Defense may know better than a contracting firm about the efficiency of a weapons system in front of other strategic forces or about the state of the latter. Furthermore it may have better information about the possibility of substitution by systems developed by other firms.[8/]

Second the investment levels, the production cost estimates, and realization (in case of implementation) are observed only by the firm. This assumption is usually made in the literature on static procurement (the use of a total cost observation as an ex-post monitoring device in such a static context is examined in Baron-Besanko [1983b] and Laffont-Tirole [1984]). Of course c_t and e_t can denote the part of the costs that cannot be observed by the sponsor if another part is observable. In an R&D procurement context there are several reasons why real costs may not be observable. As a piece of evidence let us gather the following observations made by Peck and Scherer [1962] in their extensive study of military procurement; these observations show that attempts at establishing the real cost of the firm may be considerably blurred by moral hazard and adverse selection problems.

a.)Moral hazard: the firm can manipulate costs both at the accounting and the real levels. Costs associated with another activity of the firm may be written up in the project. The firm can also change the real costs by i)shifting good engineers, or more generally priorities, from one project to another ii) using inexperienced in-house groups instead of a subcontractor in order to diversify in a new field

(p. 389) iii) not organizing work effectively, nor recruiting good personnel, etc...

Adverse selection: the sponsor usually does not know the firm's opportunity cost.[9/] This remark is particularly relevant as "undercapacity operation is quite common in the rapidly changing defense industry" (Sherer (1964), p.183).[10/]

To counter these informational problems, the sponsor must audit. Unfortunately, auditing by government agencies is usually poor (p.417). Indeed, even a highly competant accountant is unable to make judgements requiring a "sound understanding of the technology involved".

5. Incentives Under Full Commitment

In this section I study the extreme case in which both the sponsor and the firm are able to commit themselves to an intertemporal contract. I consider a sequential revelation game in which at each period the sponsor announces its expected value of the project and the firm its current cost estimate. Let $\hat{v}_t$ and $\hat{c}_t$ denote the announcements at date t. These are made simultaneously. Let $(\hat{v}^t, \hat{c}^t)$ denote the sequence of announcements up to time t (period t announcements are included).

Contracts: A binding contract specifies in period 1 for all t

- a decision rule $\delta_t(\hat{v}^t, \hat{c}^t)$, which takes values in $\{S, I, R\}$.

- an (unconditional) monetary transfer from the sponsor to the firm $x_t(\hat{v}^t, \hat{c}^t)$.

Viewing the value of the project as a monetary one, I make the following assumptions:

<u>Assumption 8</u>: The sponsor and the firm are risk neutral.

<u>Assumption 9</u>: Both the sponsor and the firm abide by the contract once it is signed.

Assumption 9 is made in this section only.

<u>Strategies</u>: A strategy for the sponsor is a sequence of announcements that are measurable with respect to its information:

$$\hat{v}_t(\hat{v}^{t-1},\hat{c}^{t-1},v_t) \quad .$$

A strategy for the firm is a sequence of announcements and investment levels (the latter conditional on $\delta_t = R$) that are measurable with respect to its information:

$$\hat{c}_t(\hat{v}^{t-1},\hat{c}^{t-1},c_t) \quad \text{and} \quad e_t(\hat{v}^t,\hat{c}^t,c_t) \quad .$$ [11]

<u>Payoffs</u>: Given strategies $\{\hat{v}_t,\hat{c}_t,e_t\}_{t=2,\dots,T}$, the sponsor's payoff is:

$$\phi_1(v_1,c_1) \equiv E\left(\sum_{t=1}^{T} \gamma^t(-x_t 1_{\{R_{t-1}\}} + v_t 1_{\{I_t\}})\right)$$

where the notation is the same as in Section 2. Similarly the firm's payoff is:

$$\Phi_1(v_1,c_1) \equiv E\left(\sum_{t=1}^{T} \gamma^t(x_t 1_{\{R_{t-1}\}} - c_t 1_{\{I_t\}} - e_t 1_{\{R_t\}})\right) \quad .$$

Note that in these definitions v_t and c_t denote the true value and cost at time t. Also w.l.o.g. the time-t transfer can be made contingent on not having been stopped or implemented by time $(t - 1)$.

Beliefs: Each party's expected payoff at any moment of time depends on the beliefs it has about the other party's information. Clearly it can gain some information by observing the other party's announcements. I will denote by $\nu_t(c|\hat{v}^{t-1},\hat{c}^{t-1})$ the sponsor's posterior probability distribution about the firm's cost at t given the common knowledge information at the end of period $(t - 1)$. Similarly let $\mu_t(v|\hat{v}^{t-1},\hat{c}^{t-1})$ denote the firm's posterior probability distribution about the sponsor's value at t given the common knowledge information at the end of period $(t - 1)$.

The two parties play a game the rules of which are defined by the binding contract. Let us now make a behavioral assumption:

Equilibrium: For a given binding contract, a perfect Bayesian equilibrium is a set of strategies $\{\hat{v}_t,\hat{c}_t\}_{t=2,\ldots,T}$ and beliefs $\{\nu_t,\mu_t\}_{t=2,\ldots,T}$ such that

(a) at any date t and for any history at time t, each party's strategy is optimal given its beliefs;

(b) at each date t, each party's beliefs are derived from the other party's strategy and observed actions using Bayes rule.

For more details about such a behavioral assumption, see Kreps-Wilson [1982].

The main result of this section states that under full commitment the first best solution characterized in Section 3 can be achieved:

Proposition 4: Under Assumptions 1 through 9, there exists a binding contract that implements the first best in perfect Bayesian strategies.

Proof: See Appendix II. Let us briefly and informally describe how such a contract can be designed.

In equilibrium the parties at each instant and for any history are induced to tell the truth: $\hat{v}_t = v_t$ and $\hat{c}_t = c_t$. Furthermore if $\delta_t = R$, the firm's investment is first best optimal relative to the sponsor announced value and the firm's true cost: $e_t = e_t^*(\hat{v}_t, c_t)$ ($= e_t^*(v_t, c_t)$ on the equilibrium path). Truth-telling has two consequences. First the decision rule must be $\delta_t(\hat{v}^t, \hat{c}^t) = \delta_t^*(\hat{v}_t, \hat{c}_t)$ in order to obtain the first-best outcome. Second, at any date and on the equilibrium path each party has full knowledge about the other party's previous period private information. The equilibrium beliefs ν_t and η_t are thus the true conditional beliefs at time $(t - 1)$.

The crux of the matter consists in defining transfers (x_t) such that both parties are induced to tell the truth. It has been shown by d'Aspremont-Gerard Varet [1979] that in a static framework it is possible to obtain truthful revelation by means of Groves-type mechanisms, i.e., mechanisms such that each party ends up facing the expected social consequence of its choice. In a static framework, where only a decision between S and I is at stake (like at period T of my model), the natural tendency for both parties is to overstate their valuation and cost: the sponsor enjoys implementation, and the firm bears its cost. To counterbalance these incentives to "lie upwards," the transfer must increase with the announced valuation and decrease with the announced cost.

The proof of Proposition 5 provides a generalization of the d'Aspremont-Gerard Varet result to dynamic stiuations (with an R region). Note first that operating d'Aspremont-Gerard Varet transfers at each instant requires updated probability distributions about the parties' private information. Therefore transfers must depend not only on the current announcements $(\hat{v}_t, \hat{c}_t)$, but also on previous periods' announcements $(\hat{v}^{t-1}, \hat{c}^{t-1})$. It turns out that, due to the Markov property of the model and to the fact that at time $(t - 1)$ the two parties have told the truth $(\hat{v}_{t-1} = v_{t-1}$ and $\hat{c}_{t-1} = c_{t-1})$, one can recover the true probability distributions before period t's announcement simply by looking one period back.[12] Second when choosing an announcement at date t, the firm takes account how its announcement $\hat{c}_t$ affects date t's decision (δ_t) and transfer (x_t) (as in d'Aspremont-Gerard Varet), but also date-$(t + 1)$ transfer and belief $(x_{t+1}$ and $\nu_{t+1})$. And similarly for the sponsor, who also takes into account the effect of $\hat{v}_t$ on e_t (if $\delta_t = R$): a higher $\hat{v}_t$ signals a higher probability of future agreement and therefore encourages the firm to invest more in the relationship. The contract must account for the fact that the parties take a dynamic perspective, i.e., that they want to hide their information at date t to be in a better position at date $(t + 1)$.

Lastly it is possible to show that, if $\delta_t = R$, the firm picks the optimal level of investment. Since the firm bears the final cost of production and there is the right amount of implementation, the firm takes the optimal investment decision unless the change in cost indirectly improves its position at the revelation stage. But it already has no interest in lying; hence by the envelope theorem, it has no incentive to distort the cost structure just to be in a more favorable negotiating position. Another way to see this is to remember that the firm ends up facing the social consequence of its actions, including investment.

Remark 1: The contract can always choose the first-period transfer so as to give the firm a zero expected intertemporal profit.

Remark 2: If the sponsor could invest at each time t in information acquisition that reduces the variance of the estimate of the value of the project, it still would be possible to construct a binding contract so as to implement the first best.

6. Commitment vs. Non-Commitment

Section 5 assumed that the two parties could bind themselves at the start. This is a very strong assumption. There are two main reasons why such a commitment--which is desirable--may not exist: transaction costs and sequental individual rationality constraints. The analysis here remains very informal as it refers to considerations outside the scope of the model.

(1) A number of contracts are signed in a rush to get the research going (see Peck-Scherer [1962], page 417 for evidence). Complete intertemporal contracts take too much time or are too costly to negotiate. Many bargainers prefer to rely on future renegotiation. This is particularly true for risky R&D projects, where design changes are the rule rather than the exception. The possibilities for design changes are vast and often unforseeable. And a small change in the design partly invalidates the initial contract.[13/]

(2) The firm may go bankrupt if at some point of time the prospects associated with the project become bleak. Similary the sponsor may go bankrupt if it is a private firm, or cancel the project if it is a government agency (Congress).

This obviously is a fairly incomplete discussion of why commitment is very incomplete in real-world procurement situations (see also Freixas-Guesnerie-Tirole [1982]). This topic deserves further study.

7. Renegotiation and Investment in the Relationship

I now assume that the firm and the sponsor bargain after obtaining information. To this purpose I take a simple <u>two-period</u> version of the general model (T = 2). At date 1 the firm invests e_1 (the sponsor does not observe e_1). At the beginning of period 2 the two parties obtain their private information $(v_2 = \tilde{V}_2$ and $c_2 = \tilde{C}_2(e_1))$. They then meet to decide whether to implement or to cancel; by assumption no information or cost reduction can be obtained anymore and hence the research option is ruled out in the second period.

Since the parties are not constrained by a binding contract, they bargain over the outcome. A potential problem is how to describe the second-period bargaining process. There are many extensive forms that can be used, and it is hard to know which one is most plausible. I avoid committing myself to a particular form of bargaining by making a simple assumption that is satisfied by the bargaining schemes that have been studied in the literature.

Let $\bar{\Phi}_2(c_2)$ denote the expected payoff of the firm in the second period. The sunk investment cost e_1 does not enter $\bar{\Phi}_2$; but the production cost c_2 does in case of implementation. Note also that $\bar{\Phi}_2$ is an expectation over v_2, and depends on the bargaining process.[14]

Let us give an example of a bargaining process that will be developed in the next section: the firm makes a take-it-or-leave-it offer p^*. Of course p^* depends on c_2: $p^*(c_2)$. The sponsor accepts the offer if and only if $p^*(c_2) \leq v_2$. For this bargaining process $\bar{\Phi}_2$ can be written:

$$\bar{\Phi}_2(c_2) = (p^*(c_2) - c_2)\Pr\{v_2 \geq p^*(c_2)\} \quad .$$

Let us now make Assumption 9', which replaces Assumption 9 from now on:

<u>Assumption 9'</u>: For almost all c_2, $\bar{\Phi}_2(c_2)$ is differentiable and

$$\left|\frac{d\bar{\Phi}_2(c_2)}{dc_2}\right| \leq \Pr\{v_2 \geq c_2\}$$

Assumption 9' says that the firm's second period expected profit does not decrease faster than the expected cost of implementation in the first best. To give an example, take the case of the firm's making a take-it-or-leave-it offer. By the envelope theorem

$$\left|\frac{d\bar{\Phi}_2}{dc_2}\right| = \Pr\{v_2 \geq p^*(c_2)\}. \text{ As clearly } p^*(c_2) > c_2, \text{ one has}$$

$$\left|\frac{d\bar{\Phi}_2}{dc_2}\right| < \Pr\{v_2 \geq c_2\} .$$

Assumption 9' actually is a very general property associated with perfect Bayesian equilibria of bargaining games. It is satisfied by:

(a) Most bargaining processes consisting of a sequence of offers and counteroffers. Examples include the firm's or the sponsor's making a take-it-or-leave-it offer, as well as the bargaining schemes considered in Cramton [1983, 1984], Fudenberg-Tirole [1983], Fudenberg-Levine-Tirole [1984], Rubinstein [1983] and Sobel-Takahashi [1983].

(b) The Chatterjee-Samuelson [1983] simultaneous offer scheme, that implements (in the uniform case) the optimal mechanism with individual rationality constraints described in Myerson-Satterthwaite [1983]; and Moore [1983]'s bilateral asymmetric information game.

In these games Assumption 9' is closely related to the firm's incentive compatibility constraint associated with equilibrium strategies. The envelope theorem shows that the derivative of $\bar{\Phi}_2$ with respect to c_2 is equal to (minus) the probability of implementation (possibly with a discount factor if bargaining is sequential). As implementation is in general suboptimal (i.e., there is less agreement than in the first best),[15/] Assumption 9' follows.

Remark: Assumption 9' can also easily be generalized to procurement situations in which there is a choice of scale (e.g., Baron-Myerson [1982]).

Let $\bar{e}_1$ denote the equilibrium investment.

Proposition 5: Under Assumptions 1, 8, and 9', the firm invests too little in the relationship: $\bar{e}_1 \leq e_1^*$, where e_1^* is the first best level.

Proof: In the first period, the firm maximizes:

$$\max_{e_1} \{- e_1 + \gamma E(\bar{\Phi}_2(\tilde{C}_2(e_1))\} \ .$$

The first-order condition is

$$- 1 + \gamma E(\frac{d\bar{\Phi}_2}{dc_2} \frac{\partial \tilde{C}_2}{\partial e_1}) = 0$$

using Assumption 9'

$$- 1 + \gamma E(Pr\{v_2 \geq \tilde{C}_2(e_1)\} \frac{\partial \tilde{C}_2}{\partial e_1}) \geq 0$$

or

$$- 1 + \gamma E(\frac{\partial \tilde{C}_2}{\partial e_1} 1_{\{v_2 \geq \tilde{C}_2(e_1)\}}) \geq 0$$

Lastly using Assumption 5 shows that $\bar{e}_1 \leq e_1^*$.

Indeed if the bargaining process is inefficient (the level of implementation is strictly suboptimal), the firm invests strictly too little in the relationship. This is the case in the bargaining processes mentioned above. Q.E.D.

The intuition behind Proposition 5 is as simple as the proof. If bargaining reduces the probability of implementation relative to commitment, the acquisition of cost-reducing technology is not as valuable as in the first best, and the firm underinvests. This is not a new idea. It simply formalizes the theory according to which ex-post bilateral monopoly reduces investment in a long-run relationship (Williamson [1975], Klein-Crawford-Alchian [1978]).

Proposition 5 is complementary to a result in Laffont-Tirole [1984]. There it is shown in a commitment context that if the firm's total cost (investment plus production) is observable and there is adverse selection at the start as well as moral hazard at the production stage, the firm underinvests in the relationship; in other words the firm's technological choice is biased against reducing production costs.

Let us now assess the effect of the non-observability of investment. To this purpose <u>assume that</u> e_1 <u>is observed by the sponsor</u> and therefore can be jointly determined. Do the parties agree on a higher or lower level of investment than the one $(\bar{e}_1)$ the firm chooses when its investment is not observable by the sponsor? I stick to my assumption that various transaction costs (design changes) and individual rationality constraints preclude the use of full commitment and require renegotiation: when signing a contract, the two parties can only agree on the level of investment and its financing.

A rough analysis of the comparison goes like this: when the firm picks its investment level $\bar{e}_1$, it does not take into account the bargaining externality on the sponsor (only for the optimal commitment mechanism built in Section 5 does it fully internalize the true social value of its investment decision). Increasing the investment reduces the cost and in general makes the firm softer in the bargaining process. So the sponsor benefits from an increase in investment. And joint determination of the investment level, when observable, ought to result in more investment. The real story however is a bit more complicated than this. Moving from non-observability to observability, one also changes the information structure in the bargaining process. The sponsor's beliefs about the firm's cost distribution change; so does the bargaining outcome for given value and cost levels.

Before making an assumption that allows comparison, let us give some more notation. Let $\bar{\Phi}_2(c_2,e_1)$ denote the firm's second period expected profit in the bargaining process when it has cost c_2 and the sponsor believes the firm has invested e_1. Similarly $\bar{\Psi}_2(c_2,e_1)$ denotes the sponsor's expected profit (over all its potential values) when the firm has cost c_2 and the sponsor believes investment e_1 has been made. For simplicity we restrict ourselves to bargaining schemes that do not involve delay in agreement, if any, or bargaining costs (one party's making an offer is an example of such a bargaining scheme). We will say that there is "more agreement (implementation)" when "the set of values and costs such that agreement is reached becomes larger."

<u>Assumption 10</u>: i) The sponsor prefers low costs:

$$c_2 < c_2' \rightarrow \bar{\Phi}_2(c_2,e_1) > \bar{\Phi}_2(c_2',e_1) \quad .$$

ii) There is at least as much agreement when the investment the sponsor believes the firm has made increases (keeping the firm's real cost distribution constant).

Let us give an example of bargaining processes that satisfy Assumption 10:

Example: The firm makes a take-it-or-leave-it offer: Assumption 10ii is trivially satisfied, as the firm's optimal offer, for a given cost level, depends only on the distribution of the government's value. So there is the same amount of agreement. Assumption 10 i--(on average) the sponsor prefers the firm's cost to be low--results from the fact that the firm's offer is an increasing function of its cost.

<u>Proposition 6</u>: Under Assumption 10, $\bar{\bar{e}}_1 \geq \bar{e}_1$, where $\bar{\bar{e}}_1$ denotes the (mutually agreed upon) investment level under investment observability.

<u>Proof</u>: Assume $\bar{e}_1 > \bar{\bar{e}}_1$. From the definitions of $\bar{e}_1$ and $\bar{\bar{e}}_1$, we have:

$$(7.1) \qquad E\{\gamma\bar{\Phi}_2(\tilde{C}_2(\bar{e}_1),\bar{e}_1)\} - \bar{e}_1 \geq E\{\gamma\bar{\Phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{e}_1)\} - \bar{\bar{e}}_1$$

$$(7.2)\qquad \begin{aligned} &E\{\gamma\bar{\Phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{\bar{e}}_1) + \gamma\bar{\phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{\bar{e}}_1)\} - \bar{\bar{e}}_1 \\ &\qquad \geq E\{\gamma\bar{\Phi}_2(\tilde{C}_2(\bar{e}_1),\bar{e}_1) + \gamma\bar{\phi}_2(\tilde{C}_2(\bar{e}_1),\bar{e}_1)\} - \bar{e}_1 \quad . \end{aligned}$$

(7.1) takes into account the fact that under non-observability, the firm can influence its cost distribution, but not the sponsor's beliefs about it (which are derived from the equilibrium investment $\bar{e}_1$). (7.2) corresponds to optimal investment under investment observability.

Adding (7.1) and (7.2) and using Assumption 10i gives:

$$(7.3)\qquad \begin{aligned} &E\{\bar{\Phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{\bar{e}}_1) + \bar{\phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{\bar{e}}_1)\} \\ &\qquad > E\{\bar{\Phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{e}_1) + \bar{\phi}_2(\tilde{C}_2(\bar{\bar{e}}_1),\bar{e}_1)\} \end{aligned}$$

Note that in (7.3) the only difference between the LHS and the RHS is the sponsor's beliefs about the firm's investment. Also

$$\bar{\Phi}_2(c_2,e_1) + \bar{\phi}_2(c_2,e_1) = E_{v_2}((v_2 - c_2)1_{\{\delta(v_2,c_2|e_1)=I\}})$$

where $1_{\{\delta(v_2,c_2|e_1)=I\}}$ is equal to one when there is agreement and to zero in case of disagreement. Assumption 10ii can be written:

$$\delta(v_2,c_2|\bar{\bar{e}}_1) = I \rightarrow \delta(v_2,c_2|\bar{e}_1) = I \quad .$$

This contradicts (7.3). Q.E.D

While assumption 10 i) is likely to be satisfied in most cases, it is easy to build examples in which assumption 10 ii) is violated and proposition 6) does not hold:[16/] <u>the observability of investment may reduce its level.</u>

A last comparison we may want to make is that between the second-best investment under observability $(\bar{\bar{e}}_1)$ and the first-best investment (e_1^*). It turns out that this comparison is ambiguous. It is not hard to find examples for which $\bar{\bar{e}}_1 < e_1^*$, because implementation is usually suboptimal for bargaining outcomes. Maybe more surprising is the fact that $\bar{\bar{e}}_1$ can exceed e_1^*. To show this consider the following simple example:

The sponsor's value can be either $\underline{v}_2$ or $\bar{v}_2$ $(\underline{v}_2 < \bar{v}_2)$ with equal probabilities. The investment technology is deterministic. There are two levels of cost $\underline{c}_2 < \bar{c}_2$ $(< \underline{v}_2 < \bar{v}_2)$. The investment cost for $\underline{c}_2(\bar{c}_2)$ is $e_1(f_1)$: $e_1 > f_1$. Assume that

$$(7.4) \qquad \underline{v}_2 - \underline{c}_2 > \frac{1}{2}(\bar{v}_2 - \underline{c}_2)$$

$$(7.5) \qquad \frac{1}{2}(\bar{v}_2 - \bar{c}_2) > \underline{v}_2 - \bar{c}_2$$

$$(7.6) \qquad e_1 + \underline{c}_2 = f_1 + \bar{c}_2 + \varepsilon$$

where $\varepsilon > 0$ is "small".[17/] (7.6) implies that the first-best investment is $e_1^* = f_1$. Assume that the firm makes a take-it-or-leave-it offer. From (7.4), it makes offer $\underline{v}_2$ if its cost is $\underline{c}_2$, so there is the optimal level of implementation. If its cost is $\bar{c}_2$, it makes offer $\bar{v}_2$ (from (7.5)), and there is suboptimal implementation. To determine $\bar{\bar{e}}_1$, we have to compare social welfare for the two possible investments:

Investment e_1: $\frac{1}{2}(\bar{v}_2 + \underline{v}_2) - (\underline{c}_2 + e_1) \equiv A$

Investment f_1: $\frac{1}{2}\bar{v}_2 - (\frac{1}{2}\bar{c}_2 + f_1) \equiv B$.

Clearly $A - B = \frac{\underline{v}_2}{2} - (\underline{c}_2 + e_1) + (\frac{1}{2}\bar{c}_2 + f_1) = \frac{\underline{v}_2 - \bar{c}_2}{2} - \varepsilon > 0$.

So the second-best investment under observability may exceed the first best level. The point is that it may be worth forcing the firm to overinvest in order to "soften" its behavior in the bargaining process, and confer positive externalities on the sponsor.

8. The Role of Cancellation Fees

Cancellation fees have been advocated in the literature as a way to reintroduce some commitment in relationships that are otherwise governed by sequential renegotiation. The party that commits itself to paying a fee if it "cancels" the project to some extent internalizes the cost it inflicts on the other party.[18] The U.S. Department of Defense has been pushing cancellation fees for some time as a way to reduce procurement costs. Its main argument is that the contractors have more incentive to invest in cost-reducing technology if they know that the government (Congress) is less tempted to act opportunistically once the investment is made (Thaler-Ugoff [1982]). Similarly Williamson [1983] has argued that "hostages" help solving the ex-post bilateral monopoly problem (for a brief account of the argument and of the difference with the one presented here, see Section 10 on related work).

Cancellation fees and hostages are popular because they are easily enforceable clauses: termination of a project can be observed by a third party. On the other hand it is very hard to know who is really responsible for the cancellation. The party that cancels may have been forced to do so by excessive demands from the other party. The very reasons that make long-run contracting impossible in general also work against a fair splitting of responsibility between the two parties by a third party. This is the clue as to why cancellation fees may not be as attractive as they look. Indeed the purpose of this section is to show that the Department of Defense view is not correct in general as it misses a crucial element: a cancellation fee influences the bargaining process by increasing the firm's power. Hence it is not clear that it helps reduce the bias toward a low level of implementation emphasized in the previous section.

Consider the two-period model used in Section 7. Assume that the investment e_1 is not observed by the sponsor; and that a cancellation fee K has to be paid by the sponsor to the firm in case of non-implementation. I will assume that $K \geqslant 0$. Performance bond requirements, i.e., bonds that are posted by the firm and are given up in case of non-delivery, can be formalized as negative cancellation fees. Contrary to cancellation fees such bonds are rarely observed (see Scherer [1964]).

Assume first that the two parties have <u>linear</u> utility functions, as has been assumed up to now. The sponsor (firm) bargains with fictitious value $(v_2 + K)$ (cost $(c_2 + K)$). For a large class of bargaining schemes, this bargaining is equivalent to that between a sponsor with value v_2 and a firm with cost c_2 over a fictitious price $q \equiv p - K$. The probability of agreement (implementation) is the same as for $K = 0$; and hence the incentive to reduce cost is the same without cancellation fee. In other words the cancellation fee has a redistributive effect (it increases the firm's income by K in all states of nature), but no allocative effect. I don't develop this point further as it will result from the analysis of a special case in the two examples below.

I now want to show that a cancellation fee can even decrease investment. To this purpose a) I assume that the parties are risk-averse; b) I consider two very special second period bargaining processes. One gives a lot of power to the firm and the other to the sponsor. In the former (the latter), the firm (sponsor) makes a second-period offer that the sponsor (firm) must take or leave. In both cases it is shown that investment can decrease with the cancellation fee.

Example 1: Firm makes a take-it-or-leave-it offer

Let us assume that the firm has utility function $\{U_1(-e_1) + \gamma U_2(p - c_2)\}$ if investment e_1 is made in the first period and agreement is reached at price p in the second period. For simplicity I assume that the firm knows the exact implementation cost c_2 at the beginning of the second period. If disagreement occurs, the firm's utility is $\{U_1(- e_1) + \gamma U_2(K)\}$ where K is the cancellation fee. U_1 and U_2 are concave. Let $G(v_2)$ denote the cumulative distribution of the sponsor's value in period 2 (with density $g(v_2)$). Again for simplicity I assume that the sponsor knows the value of the project with certainty at the beginning of the second period.

If the firm makes an offer p, the sponsor accepts the offer if and only if $v_2 - p \geqslant - K$. Therefore, in the second period, the firm maximizes:

$$\max_p \{(1 - G(p - K))U_2(p - c_2) + G(p - K)U_2(K)\}$$

Letting $q \equiv p - K$ and optimizing over q gives the first-order condition:

$$(7.7) \qquad - g(q)\ (U_2(q + K - c_2) - U_2(K)) + (1 - G(q))U_2'(q + K - c_2) = 0$$

I will assume that the second order condition is satisfied; a sufficient condition for this is that the density g is non-decreasing. Let $q^*(c_2,K)$ denote the optimum and let $p^*(c_2,K) \equiv q^*(c_2,K) + K$. (7.7) implies that $q^* > c_2$ or $p^* > c_2 + K$.

Notice that if U_2 is linear, $q^*(c_2,K)$ does not depend on K. Neither does the probability of implementation given c_2 which is $1 - G\ (q^*(c_2))$.

Let us now assume that U_2 is strictly concave. Differentiating the first-order condition and using the first- and second-order conditions gives:

$$(7.8) \qquad \frac{\partial q^*}{\partial K} \quad \left(\frac{U_2'(K) - U_2'(q^* + K - c_2)}{U_2(q^* + K - c_2) - U_2(K)}\right) - \left(- \frac{U_2''(q^* + K - c_2)}{U_2'(q^* + K - c_2)}\right) \quad ;$$

and p^* is easily shown to grow with K.

Thus the sign of $\frac{\partial q^*}{\partial K}$ is a priori ambiguous. Remember that for

$K = 0$, the level of implementation is suboptimal (as the bargaining scheme satisfies Assumption 9'); if $\frac{\partial q^*}{\partial K} > 0$, then a cancellation fee reduces implementation even more ($G(q^*)$ increases). This is the case for example for a logarithmic U_2.

Let us now investigate the effect of a cancellation fee on first-period investment. Using the envelope theorem, e_1 is given by:

$$- U_1'(- e_1) - \gamma E[(1 - G(q^*(c_2,K)))U_2'(q^*(c_2,K) + K - c_2) \frac{\partial \tilde{C}_2}{\partial e_1}] = 0 \quad .$$

Assuming that the second-order condition is satisfied, we obtain:

$$(7.9) \qquad \frac{\partial e_1}{\partial K} \quad \gamma E[g(q^*)\frac{\partial q^*}{\partial K} U_2' \frac{\partial \tilde{C}_2}{\partial e_1} - (1 - G(q^*))U_2'' \frac{\partial p^*}{\partial K} \frac{\partial \tilde{C}_2}{\partial e_1}] \quad .$$

Note that if U_2 is linear, the cancellation fee has no influence on investment. Assuming now that U_2 is strictly concave, we can distinguish two terms inside the expectation in (7.9).

(a) The first term corresponds to the change in implementation. If the cancellation fee reduces implementation ($\frac{\partial q^*}{\partial K} > 0$), it also tends to reduce investment (as $\frac{\partial \tilde{C}_2}{\partial e_1} < 0$). This is now a usual effect.

(b) The second term unambiguously leads to less investment (as $\frac{\partial p^*}{\partial K} > 0$, $\frac{\partial \tilde{C}_2}{\partial e_1} < 0$, $U_2'' < 0$). The point is that a cancellation fee increases the price. Therefore it decreases the marginal utility of income for the firm in case of agreement, and thus reduces the desirability of cost-reducing investment.

Let us now examine the special case of a constant absolute risk aversion U_2: $U_2(x) = - e^{-\theta x}$ $(\theta > 0)$.

Proposition 7: Under Assumptions 1-8, if the firm makes the second-period offer and has a constant absolute risk aversion second-period utility function, its first-period investment decreases with the cancellation fee.

Proof: (7.8) implies that $\frac{\partial q^*}{\partial K} = 0$, so that implementation does not depend on the cancellation fee. The analysis of (7.9) then implies that $\frac{\partial e_1}{\partial K} < 0$. Q.E.D.

Example 2: Sponsor Makes Offer

The analysis is a bit more complicated than, but similar to that of Example 1, and will only be mentioned here. It is also possible to show that, for a given level of cost, the effect of a cancellation fee on implementation is in general ambiguous. For example if the sponsor is risk neutral, the level of implementation does not depend on K. Furthermore, if $C_2 = \theta_2 h(e_1)$ where θ_2 is uniformly distributed, a strictly risk-averse firm invests strictly less when the cancellation fee increases by a reasoning similar to the analysis of equation (7.9).[19/]

We have seen that a cancellation fee may well reduce investment in the relationship contrary to the prevailing opinion on the matter. A possible solution to this problem is to ensure that the cancellation fee does not make the firm too demanding in the bargaining process. This is achieved if the firm receives only a fraction of what the sponsor loses in case of cancellation.[20/] Such agreements however are rarely observed, as there is an ex-post common incentive to disguise cancellation in order to avoid an aggregate loss.

9. Cost Overruns

Cost overruns have always been a concern to economists and politicians. Peck and Scherer estimate that for U.S. defense programs development costs exceed original predictions by 220% on average; in some cases costs have exceeded original predictions by as much as 14 times ([1962], pp. 412, 429). More recent estimates in different countries as well as the recent political debate in the U.S. about the use of military spending also indicate that procurement costs are a serious problem.

An economist's natural analysis of cost overruns is that costs may be "high" due to agency problems, but that in a Rational Expectations world they are not unforeseen on average. The study of renegotiation suggests that high costs result from the related problems of ex-post bilateral monopoly and underinvestment. But the sponsor ought to anticipate these inefficiencies. So "cost overruns" may be taken to mean "agency costs."

The fundamental question about "systematic unforeseen cost overruns" is the meaning of original cost estimates, i.e., the level of commitment attached to these estimates. In particular, what is the status of an original price estimate when the parties know that the firm will bear only a small share of overruns, as seems to be the case for military procurement?

One hypothesis is that the original price estimate represents only a lower bound on the transfer in case of implementation. It would be the equivalent in case of implementation of a cancellation fee in case of termination. It would then be a minimum commitment from the sponsor. The sponsor however would not want to commit itself too much as it usually is fairly difficult to later be reimbursed by the firm (as in the case in France and in the U.S.). This interpretation is in the spirit of "redeterminable fixed-price contracts," in which the partners negotiate a tentative base price and then, after some share of expected costs has been incurred, renegotiate a new price. I should add that all this is pure conjecture as I was not able to find evidence on the degree of commitment associated with cost estimates.

I also believe that the description of procurement as a two-tier relationship, if enlightening, is fairly restrictive. If higher-order hierarchies are considered, the supervisor and the agent may well have common interests. In the case of military procurement for instance, it is well-known that the services' (Delegation Generale a l'Armement in France or Department of Defense in the U.S.) interests do not coincide with the nation's. To quote Scherer ([1964], p. 28): "As the advocates of new programs, government operating agencies have often encouraged contractors to estimate costs optimistically, recognizing that higher headquarters might be shocked out of supporting a program whose true costs were revealed at the outset;" and Peck-Scherer ([1962], p. 412): "There is a tacit assumption (between the services and the contractors) that 'we'll work with this low figure for a while. If the program looks good, we can go back later and get an increase.'" This however does not mean that cost overrruns are unforeseen (except officially) by higher headquarters or the Congress. One may think of the Government Agency and the Congress as playing a revelation game with non-identical preferences (in the style of Crawford-Sobel [1982] and Green-Stokey [1980]). Such a game typically has many equilibria and can give rise to phenomena resembling grade (or letters of recommendation) inflation.

10. Related Work

This paper has studied sequential decision-making and investment in a relationship under full commitment and renegotiation. It is related to some recent and interesting work in the area.

Baron and Besanko ([1983a], Section 4) study a two-period planning model in which the firm invests in the relationship. The planner commits itself to an intertemporal incentive scheme in period one while the firm's commitment is restricted by its possibly leaving the relationship at the beginning of period two (second period individual rationality constraint). This is a model of one-sided commitment. The emphasis of their paper is different from the one here. They focus on adverse selection at the start. And incomplete information is only one-sided as the value of the output/project is common knowledge. An interesting application of their analysis for my model is that if there is no initial adverse selection, the firm's sequential individual rationality constraints (the firm may leave the relationship-- go bankrupt -- at any period) can easily be made non-binding (as long as the firm does not want to smooth its intertemporal stream of profits): it suffices that the firm pays a high enough entry fee and that it thereafter gets generous transfers that induces it not to renege on the contract. This shows that the analysis of Section 5 still holds if only one party (the sponsor) can commit itself fully to an intertemporal mechanism and the other (the firm) has a restricted commitment in the sense that it can comply with the mechanism or leave.

Proposition 5 - underinvestment on the relationship - considerably generalizes previous similar results, in particular that of Grout (1984). Grout showed in a labor contract framework that the firm underinvests in capital if it ex-post bargains with the union under symmetric information and using the Nash bargaining silution.

Crawford [1983b] studies a two-period renegotiation problem. One of the parties makes a first-period investment; and the two parties bargain in the second period about the common use of this investment. The emphasis is not on incentive problems (there is no explicit informational asymmetry), but on the interference of future individual rationality constraints or bargaining with the parties' intertemporal smoothing of income (in the spirit of Holmstrom [1983]). In Crawford's paper the absence of commitment and capital markets prevents intertemporal smoothing of profits and utilities. This affects the intertemporal path of marginal utilities of profits and thus the desirability of investment. Crawford shows that there is no presumption for underinvestment. As I ruled out the need for intertemporal smoothing of income, the Crawford effect did not arise in Section 7 and I did obtain underinvestment, at least if investment is not observed by the sponsor.[21/]

The underinvestment result is of course one of the main concerns of Williamson's [1975] book. Williamson has forcefully argued that "opportunism" (i.e., renegotiation) is a threat to the accumulation of specific assets. More recently [1983] he has studied the role of "hostages" in ensuring a right amount of specific investment. In his model as in Crawford's, investment can be observed by both parties. The firm (in my terminology) can either not invest in the relationship and later use a costly general purpose technology, or invest some fixed and positive amount in specific skills or machinery. It is assumed that in a first-best world this investment is desirable. Only the "sponsor"'s ex-post (second period) value is private information; it makes a take-it-or-leave-it offer to the firm in the second period. Efficiency arises if the sponsor posts a bond <u>equal to</u> the specific investment and loses it to the firm if the firm has actually made the investment <u>and</u> the project is cancelled. So if the specific investment is made, the firm's second-period income is raised by the amount of the bond, i.e., of the investment, in all states of nature (as argued in Section 8 this property holds for more general bargaining schemes and for bilateral asymmetric information). Furthermore the level of implementation is efficient, as it is independent of the size of the bond, and the sponsor, who makes the offer, has full information about the firm. Hence the firm has no incentive not to invest at the first best level.

My conclusion on the role of hostages (cancellation fees) differs considerably from Williamson's. The main difference is that I posited the specific investment is not observable by the sponsor, which, I argued in Section 4, is a reasonable assumption in a number of procurement situations. Then the size of the hostage cannot depend on the level of specific investment, which suppresses the channel through which a hostage gives the right incentive to invest. Indeed I argued that there is no presumption that hostages encourage specific investment at all.

When specific investment is observable by the sponsor, then the two parties can agree in advance on how to share its cost. The hostage technology is a roundabout way to do so. Under investment observability, the main issue is not the financing of the investment cost, but the determination of its level (see Section 7).

Appendix I

Characterization of the First Best Policy

Proposition 1: $\delta_t^*(v,c) = S \rightarrow \delta_t^*(v',c') = S$ for $v' \leq v$ and $c' \geq c$ (with one inequality at least).

Proof: (i) $\delta_t^*(v,c) = S \rightarrow v \leq c \rightarrow v' < c'$ and therefore the planner will not implement.

(ii) If W_{t+1} denotes the valuation at the beginning of $(t+1)$, for any realization of η_t and θ_t,

$$W_{t+1}(V_{t+1}(v,\eta_t),C_{t+1}(c,\theta_t,e_t)) > W_{t+1}(V_{t+1}(v',\eta_t),C_{t+1}(c',\theta_t,e_t))$$

for any e_t.

Therefore if $\max\limits_{e_t} (- e_t + \gamma E(W_{t+1}|e_t,v,c)) \leq 0$

$$\max_{e_t} (- e_t + \gamma E(W_{t+1}|e_t,v',c')) < 0$$

and the planner does not want to do R & D either.Q.E.D.

Proposition 2: $\delta_t^*(v,c) = I \rightarrow \delta_t^*(v',c') = I$ for $v' \geq v$ and $c' \leq c$ (with one inequality at least).

Proof: Clearly the planner won't stop: $v' - c' > v - c > 0$. Will he do R & D? If he did, we would have

$$v - c \geq \max_{e_t} [- e_t + \gamma E(W_{t+1}|v,c,e_t)]$$

$$v' - c' \leq \max_{e_t} [- e_t + \gamma E(W_{t+1}|v',c',e_t)]$$

Let e'_t denote the optimal R & D investment when the state is (v',c') at t. We have

$$(v' - c') - (v - c) \leqslant \gamma[E(W_{t+1}|v',c',e'_t) - E(W_{t+1}|v,c,e'_t)]$$

To obtain a contradiction, it suffices to show that for any time s, $W_s(v,c)$ does not increase as fast as v and does not decrease as fast as c. This is clear at time T: $W_T(v,c) = \max\{0, v - c\}$. At time (T-1):

$W_{T-1}(v,c) = v - c$ if one implements

$W_{T-1}(v,c) = 0$ if one stops

$$W_{T-1}(v,c) = \max_{e_{T-1}} \{- e_{T-1} + E(\gamma W_T(\tilde{V}_T(v_{T-1}),\tilde{C}_T(c_{T-1},e_{T-1}))\}$$

Using the assumption that $\frac{\partial \tilde{V}_T}{\partial v_{T-1}} \leqslant 1$ and $\frac{\partial \tilde{C}_T}{\partial c_{T-1}} \leqslant 1$, we obtain the conclusion for (T-1). By induction this is true for all s.

Q.E.D.

<u>Proposition 3:</u> In the R & D region, e^*_t grows with v_t.

<u>Proof:</u> The first-order condition for e^*_t is

$$- 1 + \gamma E(- \frac{\partial \tilde{C}_{t+1}}{\partial e_t} 1_{\{\delta^*_{t+1}=I\}}) + \gamma E(\frac{\partial W^R_{t+1}}{\partial c_{t+1}} \frac{\partial \tilde{C}_{t+1}}{\partial e_t} 1_{\{\delta^*_{t+1}=R\}}) = 0$$

where W^R_{t+1} denotes the valuation at (t+1) when one decides to do R & D at (t+1) ($W_{t+1} = W^R_{t+1}$ if $\delta^*_{t+1} = R$). In the whole proof we will assume that $\frac{\partial W^R_{t+1}}{\partial c_{t+1}}$ and $\frac{\partial^2 W^R_t}{\partial c_{t+1}\partial v_{t+1}}$ exist almost surely, which can easily be proved by backward induction (the valuation function is not differentiable at the border of the $\{\delta^*_{t+1} = R\}$ region; but from Propositions 1 and 2, this border has probability zero at time t).

Differentiating the first-order condition with respect to e_t and v_t, we get:

$$[\ -\ ]\ de_t + [\gamma E(\frac{\partial^2 W^R_{t+1}}{\partial c_{t+1}\partial v_{t+1}} \quad \frac{\partial \tilde{V}_{t+1}}{\partial v_t} \quad \frac{\partial \tilde{C}_{t+1}}{\partial e_t}) 1_{\{\delta^*_{t+1} = R\}}$$

$$+ \int_{\{R\to I\}} (- \frac{\partial \tilde{C}_{t+1}}{\partial e_t} (1 + \frac{\partial W^R_{t+1}}{\partial c_{t+1}})) + \int_{\{S\to I\}} (- \frac{\partial \tilde{C}_{t+1}}{\partial e_t})$$

$$+ \int_{\{S\to R\}} (\frac{\partial W^R_{t+1}}{\partial c_{t+1}} \quad \frac{\partial \tilde{C}_{t+1}}{\partial e_t})]dv_t = 0$$

where the coefficient of de_t is negative by Assumption 5, the symbol $\int_{\{R\to I\}}$ means "integral over (Θ_t, η_t) such that when the investment increases from e_t to $(e_t + de_t)$, the decision at time $(t+1)$ switches from R to I," and similarly for $\int_{\{S\to I\}}$ and $\int_{\{S\to R\}}$. From Propositions 1 and 2 and $\frac{\partial \tilde{C}_{t+1}}{\partial e_t} \leqslant 0$, we know that these switches are the only possible ones.

Now if we can show that

$$0 \geqslant \frac{\partial W^R_{t+1}}{\partial c_{t+1}} \geqslant -1$$

(I)

$$0 \geqslant \frac{\partial^2 W^R_{T+1}}{\partial c_{T+1}\partial c_{T+1}}$$

then using $\frac{\partial \tilde{V}_{t+1}}{\partial v_t} > 0$ and $\frac{\partial \tilde{C}_{t+1}}{\partial e_t} < 0$, we obtain: $\frac{\partial e^*_t}{\partial v_t} \geqslant 0$.

Let us show (I) by backward induction. These conditions clearly are satisfied at T $(W^R_T \equiv 0)$. Assume that they hold at $(t+1)$. Let us show that they then hold at t. First

$$\frac{\partial W^R_t}{\partial c_t} = \gamma E\left(-\frac{\partial \tilde{C}_{t+1}}{\partial c_t} 1_{\{\delta^*_{t+1}=I\}}\right) + \gamma E\left(\frac{\partial W^R_{t+1}}{\partial c_{t+1}} \frac{\partial \tilde{C}_{t+1}}{\partial c_t} 1_{\{\delta^*_{t+1}=R\}}\right) \text{ using}$$

$\gamma < 1$, $0 \leqslant \frac{\partial \tilde{C}_{t+1}}{\partial c_t} \leqslant 1$ and $0 \geqslant \frac{\partial W_{t+1}}{\partial c_{t+1}} \geqslant -1$, we get $0 \geqslant \frac{\partial W^R_t}{\partial c_t} \geqslant -1$.

Next

$$\frac{\partial}{\partial v_t}\left(\frac{\partial W^R_t}{\partial c_t}\right) = \gamma\Big[E\Big(\frac{\partial^2 W^R_{t+1}}{\partial c_{t+1}\partial v_{t+1}} \frac{\partial \tilde{V}_{t+1}}{\partial v_t} \frac{\partial \tilde{C}_{t+1}}{\partial c_t} 1_{\{\delta^*_{t+1}=R\}}\Big)$$

$$+ \int_{\{R\to I\}} \left(-\frac{\partial \tilde{C}_{t+1}}{\partial c_t}\right)\left(1 + \frac{\partial W^R_{t+1}}{\partial c_{t+1}}\right) + \int_{\{S\to I\}} \left(-\frac{\partial \tilde{C}_{t+1}}{\partial c_t}\right)$$

$$+ \int_{\{S\to R\}} \frac{\partial W^R_{t+1}}{\partial c_{t+1}} \frac{\partial \tilde{C}_{t+1}}{\partial c_t}\Big]dv_t$$

where:

a) $\int_{\{R\to I\}}$ denotes the integral over $(\theta_{t+1}, \eta_{t+1})$ such that, when the current value increases from v_t to $(v_t + dv_t)$, period $(t+1)$ decision switches from R to I. And similarly for $\int_{\{S\to I\}}$ and $\int_{\{S\to R\}}$.
$\frac{\partial V_{t+1}}{\partial v_t} \geqslant 0$, since only possible switches.

b) $\dfrac{\partial \tilde{V}_{t+1}}{\partial v_t} \geqslant 0$, $\dfrac{\partial \tilde{C}_{t+1}}{\partial c_t} \geqslant 0$ and by induction, $\dfrac{\partial^2 W^R_{t+1}}{\partial c_{t+1} \partial v_{t+1}} \leqslant 0$ and

$- 1 \leqslant \dfrac{\partial W^R_{t+1}}{\partial c_{t+1}} \leqslant 0.$

Hence $\dfrac{\partial^2 W^R_t}{\partial c_t \partial v_t} \leqslant 0.$ Q.E.D.

Appendix II

Implementation of the first best.

Proposition 4: Let us construct a series of transfers x_t from the sponsor to the firm and of decisions $\delta_t \varepsilon \{S,R,I\}$ so that the correct amounts of implementation and investment be chosen.

At each period t (until implementation or stopping), the firm announces a current cost $\hat{c}_t$ and the sponsor announces a current value $\hat{v}_t$.

Let $\delta_t^*(v_t,c_t)$ and $e_t^*(v_t,c_t)$ denote the optimal decision under symmetric information and the corresponding optimal investment if $\delta_t^* = R$.

We build a sequential revelation game in which telling the truth is optimal at each period. If we want to implement the first best, it must be the case that

$$V(\hat{v}_t,\hat{c}_t), \quad \delta_t(\hat{v}_t,\hat{c}_t) = \delta_t^*(\hat{v}_t,\hat{c}_t) \quad .$$

The transfers we will construct by backward induction look only one period back:

$$x_t(\hat{v}_t,\hat{c}_t,\hat{v}_{t-1},\hat{c}_{t-1}) \quad .$$

The equilibrium strategies at each instant will be

Sponsor: Always tells the truth (whatever the history, i.e., whether or not it has told the truth in the past).

Firm: Always tells the truth and makes optimal investment $e_t^*(\hat{v}_t, c_t)$ (whatever the history, i.e., whether or not it has told the truth and made the optimal effort in the past).

The equilibrium beliefs at each instant t will be:

Sponsor: Always believes that the firm has told the truth and made the optimal investment given the announcements up to time t.

Firm: Always believes that the government has told the truth up to time t.e

Period T: Define

$$x_T(\hat{v}_T, \hat{c}_T, \hat{v}_{T-1}, \hat{c}_{T-1}) \equiv \int_0^{\hat{c}_T} c \frac{d}{dc} \Pr \{\tilde{V}_T(\hat{v}_{T-1}) \geq c\} dc$$

$$+ \int_0^{\hat{v}_T} v \frac{d}{dv} \Pr\{v \geq \tilde{C}_T(\hat{c}_{T-1}, e^*_{T-1}(\hat{v}_{T-1}, \hat{c}_{T-1}))\} dv + z_T$$

where z_T is a constant. Note that the transfer makes use of probability distributions computed under the assumption that the two parties have told the truth and the firm has made the optimal level of investment at (T-1).

Claim: Telling the truth at T is an optimal strategy for each party if the other party tells the truth and has told the truth in the past.

Proof: Firm:

$$\max_{\{\hat{c}_T\}} \{E(x_T(\hat{v}_T,\hat{c}_T,\hat{v}_{T-1},\hat{c}_{T-1})) - c_T \Pr\{\tilde{V}_T(\hat{v}_{T-1}) \geq \hat{c}_T\}\}$$

The first order condition is:

$$(\hat{c}_T - c_T) \frac{d}{d\hat{c}_T} \Pr\{\tilde{V}_T(\hat{v}_{T-1}) \geq \hat{c}_T\} = 0$$

and the second order condition at $\hat{c}_T = c_T$ is

$$\frac{d}{d\hat{c}_T} \Pr\{\tilde{V}_T(\hat{v}_{T-1}) \geq \hat{c}_T\} \leq 0$$

The second order condition is clearly satisfied and the firm's objective function is quasi-concave, as $\hat{c}_T = c_T$ is the only solution to the first order condition. Thus telling the truth is optimal for the firm.

Sponsor:

$$\max_{\{\hat{v}_T\}} \{v_T \Pr\{v_T \geq \tilde{C}_T(c_{T-1},e^*_{T-1}(v_{T-1},c_{T-1}))\}$$

$$- Ex_T(\hat{v}_T,\hat{c}_T,\hat{v}_{T-1},\hat{c}_{T-1})\}$$

This deserves some comment. The sponsor assumes not only that the firm has told the truth last period $(\hat{c}_{T-1} = c_{T-1})$ and tells the truth this period $(\hat{c}_T = c_T)$, but also that the firm has made the optimal investment $e^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1})$. We will show later that it is indeed optimal for the firm to make the right amount of investment given that it believes that the sponsor tells the truth at each period.

The first order condition is:

$$(v_T - \hat{v}_T)\,\frac{d}{d\hat{v}_T}\,\Pr\{\hat{v}_T \geq \tilde{C}_T(\hat{c}_{T-1}, \overset{*}{e}_{T-1}(\hat{v}_{T-1}, \hat{c}_{T-1}))\} = 0$$

and the second order condition at $\hat{v}_T = v_T$ is

$$-\frac{d}{d\hat{v}_T}\,\Pr\{\hat{v}_T \geq \tilde{C}_T(\hat{c}_{T-1}, \overset{*}{e}_{T-1}(\hat{v}_{T-1}, \hat{c}_{T-1}))\} \leq 0 \quad .$$

Thus the sponsor's objective function at T is quasi-concave, and telling the truth is optimal for the sponsor.

Period (T-1)

Claim: Assume $\hat{\delta}_{T-1}(\hat{v}_{T-1}, \hat{c}_{T-1}) = R$. Whether or not the firm has told the truth at (T-1), if it presumes that the sponsor has told the truth $(\hat{v}_{T-1} = v_{T-1})$, it makes the optimal investment:

$$e_{T-1} = \overset{*}{e}_{T-1}(\hat{v}_{T-1}, c_{T-1}) \quad .$$

Proof: By the envelope theorem, the derivative of the firm's expected profit at T with respect to c_T is:

$$-\Pr\{\tilde{V}_T(\hat{v}_{T-1}) \geq c_T\} \quad .$$

It clearly does not depend on what the firm announced at (T-1). But since the sponsor has told the truth $(\hat{v}_{T-1} = v_{T-1})$, the incentive to cost reduction is the same as the social incentive. Thus:

$$e_{T-1} = \overset{*}{e}_{T-1}(\hat{v}_{T-1}, c_{T-1}) \quad .$$

Q.E.D.

Next define the following valuation functions:

(A) $\Phi_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1},c_{T-1})$ is the firm's expected profit net of investment at $(T-1)$ given that

(0) the firm's cost is c_{T-1}

(1) the sponsor told the truth: $\hat{v}_{T-1} = v_{T-1}$

(2) the decision is $\delta_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = R$

(3) the firm is about to make investment $e^*_{T-1}(\hat{v}_{T-1},c_{T-1})$

(4) both will tell the truth at time T

(period $(T-1)$ investment enters Φ_{T-1}; period $(T-1)$ transfer does not).

(B) $\phi_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1},v_{T-1})$ is the expected profit for the sponsor at $(T-1)$ given that

(0) the sponsor's valuation is v_{T-1}

(1) the firm told the truth at $(T-1)$: $\hat{c}_{T-1} = c_{T-1}$

(2) $\delta_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = R$

(3) the firm makes investment $e^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1})$

(4) both will tell the truth at time T

(period $(T-1)$ transfer does not enter ϕ_{T-1}).

Define the following transfer function:

$$\text{(C)}\quad x_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1},\hat{v}_{T-2},\hat{c}_{T-2}) \equiv \int_{o}^{\hat{c}_{T-1}}[c \frac{d}{dc} \Pr\{\delta^*_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),c) = I\}$$

$$- \frac{d}{dc}\{E(\Phi_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),c,d)1_{\{\delta^*_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),c) = R\}})\}\Big|_{d=c} \approx dc$$

$$+ \int_{o}^{\hat{v}_{T-1}}[v \frac{d}{dv} \Pr\{\delta^*_{T-1}(v,\tilde{C}_{T-1}(\hat{c}_{T-2},e^*_{T-2}(\hat{v}_{T-2},\hat{c}_{T-2}))) = I\}$$

$$+ \frac{d}{dv}\{E(\phi_{T-1}(v,\tilde{C}_{T-1}(\hat{c}_{T-2},e^*_{T-2}(\hat{v}_{T-2},\hat{c}_{T-2})),u)$$

$$1_{\{\delta^*_{T-1}(v,\tilde{C}_{T-1}(\hat{c}_{T-2},e^*_{T-2}(\hat{v}_{T-2},\hat{c}_{T-2}))) = R\}})\}\Big|_{u=v} \approx dv$$

$$+ z_{T-1}$$

where z_{T-1} is a constant and $1_{\{A\}}$ denotes the characteristic function of A.

Sponsor: Assume that the sponsor believes that the firm has told the truth at $(T-2)$, has made investment $e^*_{T-2}(\hat{v}_{T-2}, \hat{c}_{T-2})$ and tells the truth at $(T-1)$.

The first order condition for the sponsor's optimization problem is:

$$\text{(D)}\quad (v_{T-1} - \hat{v}_{T-1}) \frac{d}{d\hat{v}_{T-1}} \Pr\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = I\}$$

$$+ \frac{d}{d\hat{v}_{T-1}}\{E(\phi_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1},u)1_{\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = R\}})\}\Big|_{u=v_{T-1}}$$

$$- \frac{d}{d\hat{v}_{T-1}}\{E(\phi_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1},u)1_{\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1})=R\}})\}\Big|_{u=\hat{v}_{T-1}} = 0$$

where the arguments of $\hat{c}_{T-1}$ have been omitted for notational simplicity.

Clearly $\hat{v}_{T-1} = v_{T-1}$ satisfies the FOC. Actually this is the only value that satisfies the first order condition. The proof of this fact will be a by-product of the analysis of the second order condition.

The second order condition, which we take at $\hat{v}_{T-1} = v_{T-1}$ for the moment, can be written:

$$(E) \quad -\frac{d}{d\hat{v}_{T-1}} \Pr\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = I\}$$

$$-\frac{\partial}{\partial u}\left(\frac{d}{d\hat{v}_{T-1}} E(\phi_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1},u)1_{\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1})=R\}})\right)\Big|_{u=\hat{v}_{T-1}} \leq 0 \; .$$

The second term in this inequality can be written

$$\frac{d}{d\hat{v}_{T-1}} E\left((-\gamma \frac{\partial \tilde{V}_T}{\partial v_{T-1}})1_{\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = R \text{ and } \delta^*_T(\tilde{V}_T,\tilde{C}_T) = I\}}\right)$$

since, by the envelope theorem,

$$\frac{\partial \phi_{T-1}}{\partial v_{T-1}} = \gamma E\left(\frac{\partial \tilde{V}_T}{\partial v_{T-1}} 1_{\{\delta^*_T(\tilde{V}_T,\tilde{C}_T) = I\}}\right) \; .$$

Thus we have to show that

$$(F) \quad \frac{d}{d\hat{v}_{T-1}} \left| E\left[1_{\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = I\}} + \gamma \frac{\partial \tilde{V}_T}{\partial v_{T-1}} 1_{\{\delta^*_{T-1}(\hat{v}_{T-1},\hat{c}_{T-1}) = R \text{ and } \delta^*_T(\tilde{V}_T,\tilde{C}_T) = I\}}\right] \right| >$$

When $\hat{v}_{T-1}$ increases, we know from Propositions 1 and 2 that δ^*_{T-1} can only switch from S to I, S to R or R to I. Consider an increase in $\hat{v}_{T-1}$:

(1) If δ^*_{T-1} switches from S to I, the term inside the expectation in (F) increases by 1.

(2) If δ^*_{T-1} switches from R to I, the term inside the expectation increases by (at least) $(1 - \gamma \frac{\partial \tilde{V}_T}{\partial v_{T-1}}) > 0$ (by Assumption 3).

(3) If δ^*_{T-1} switches from S to R, the term inside the expectation increases by 0 or $(\gamma \frac{\partial \tilde{V}_T}{\partial v_{T-1}}) > 0$ depending on the realizations of the random variables at T.

(4) Lastly, e_{T-1} increases (Proposition 3). This effect increases the probability of implementation at T: the term inside the expectation increases by 0 or $(\gamma \frac{\partial \tilde{V}_T}{\partial v_{T-1}}) > 0$.

Thus the expectation can only increase with $\hat{v}_{T-1}$. The second order condition is thus satisfied at $\hat{v}_{T-1} = v_{T-1}$.

Let us now show that $\hat{v}_{T-1} = v_{T-1}$ is the only value that satisfies the first order condition. Let $\lambda(\hat{v}_{T-1}, v_{T-1})$ denote the left-hand side of (D). We already know that for each $\hat{v}_{T-1}$, $\lambda(\hat{v}_{T-1}, \hat{v}_{T-1}) = 0$. Differentiating (D) gives for each $\hat{v}_{T-1}$:

$$\lambda_2(\hat{v}_{T-1},v_{T-1}) = -\lambda_1(v_{T-1},v_{T-1}).$$

where λ_i denotes the partial derivative of λ w.r.t. its i^{th} argument (in other words this equality does not hold simply at $\hat{v}_{T-1} = v_{T-1}$, but for all $\hat{v}_{T-1}$). Thus the analysis of the second order condition at $\hat{v}_{T-1} = v_{T-1}$ also implies that for all $(\hat{v}_{T-1},v_{T-1})$

$$\lambda_2(\hat{v}_{T-1},v_{T-1}) \geqslant 0 \quad .$$

Now imagine that there exists $\hat{v}_{T-1} \neq v_{T-1}$ such that:

$$\lambda(\hat{v}_{T-1},v_{T-1}) = \lambda(v_{T-1},v_{T-1}) = 0 \quad .$$

Then $\lambda(\hat{v}_{T-1},v_{T-1}) = \lambda(\hat{v}_{T-1},\hat{v}_{T-1})$, which is inconsistent with λ increasing in its second argument (if λ does not strictly increase in its second argument, it must be that the probability of current or future implementation is zero, i.e., that we are in the stopping-zone with probability one. Then a small change in $\hat{v}_{T-1}$ has no effect on the sponsor's payoff, and thus we already knew directly that the objective function was locally quasi-concave).

<u>Firm</u>: Assume that the firm believes that the sponsor has told the truth at (T-2) and tells the truth at (T-1).

The first order condition for the firm's optimization problem at (T-1) is:

$$(\hat{c}_{T-1} - c_{T-1}) \frac{d}{d\hat{c}_{T-1}} \Pr\{\delta^*_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1}) = I\}$$

$$+ \frac{d}{d\hat{c}_{T-1}} \left[E(\Phi_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1},d)1_{\{\delta^*_{T-1}(\hat{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1})=R\}})\right]\Big|_{d=c^{T-1}}$$

$$- \frac{d}{d\hat{c}_{T-1}} [E(\Phi_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1},d) 1_{\{\delta^*_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1})=R\}})\approx\Big|_{d=\hat{c}_{T-1}} = 0$$

Clearly $\hat{c}_{T-1} = c_{T-1}$ satisfies the first order condition.

The second order condition at c_{T-1} can be written:

$$\frac{d}{d\hat{c}_{T-1}} \Pr\{\delta^*_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1}) = I\}$$

$$- \frac{\partial}{\partial d} \frac{d}{d\hat{c}_{T-1}} [E(\Phi_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1},d) 1_{\{\delta^*_{T-1}(\tilde{V}_{T-1}(\hat{v}_{T-2}),\hat{c}_{T-1})=R\}})\Big|_{\substack{d=\hat{c}_{T-1}\\ =c_{T-1}}}$$

$$\leq 0$$

Now $\frac{\partial\phi_{T-1}}{\partial c_{T-1}} = - \gamma E(\frac{\partial\tilde{C}_T}{\partial c_{T-1}} 1_{\{\delta^*_T(\tilde{V}_T,\tilde{C}_T)=I\}})$ by the envelope theorem. Thus we want to show that:

$$\text{(G)} \quad \frac{d}{d\hat{c}_{T-1}} E[1_{\{\delta^*_{T-1}=I\}} + (\gamma \frac{\partial\tilde{C}_T}{\partial c_{T-1}}) 1_{\{\delta^*_{T-1}=R \text{ and } \delta^*_T=I\}}\approx < 0 .$$

Notice that $0 \leq (\gamma \frac{\partial\tilde{C}_T}{\partial c_{T-1}}) < 1$ (Assumption 3), and that $\frac{\partial\tilde{C}_T}{\partial c_{T-1}}$ does not depend on $\hat{c}_{T-1}$ (since the investment strategy depends only on the true cost). When $\hat{c}_{T-1}$ increases, we know from propositions 1 and 2 that δ^*_{T-1} can only switch from I to R or S or from R to S.

(1) If δ^*_{T-1} switches from I to R, the term inside the expectation in (G) decreases by $(1 - \gamma \frac{\partial \tilde{C}_T}{\partial c_{T-1}}) > 0$ or 1 depending on the realizations of future random variables.

(2) If δ^*_{T-1} switches from I to S, the term inside the expectation decreases by 1.

(3) If δ^*_{T-1} switches from R to S, the term inside the expectation decreases by $(\gamma \frac{\partial \tilde{C}_T}{\partial c_{T-1}}) \geq 0$ or 0.

Thus the second order condition at $\hat{c}_{T-1} = c_{T-1}$ is satisfied. The proof that $\hat{c}_{T-1} = c_{T-1}$ is the only solution to the first order condition is similar to that for the sponsor.

Induction: The rest of the proof is by backward induction. To construct the transfers at time t, it suffices to define the functions Φ_t and ϕ_t by backward induction, the same way it was done in (A) and (B). Equation (C) then gives period t transfer by simply substituting t for $(T-1)$.

Thus we have shown that we could construct sequential transfers and a decision rule such that the presumed strategies form a Perfect Bayesian equilibrium. Q.E.D.

Footnotes

1/ See, e.g., Marschak and Yahav [1966] and the work of De Groot and Chernoff on sequential experiments.

2/ See, e.g., Weitzman [1979] and Weitzman-Roberts [1981].

3/ For a static theory of the principal-agent relationship, see, e.g., Ross [1973], Mirrlees [1975], Shavell [1979], Holmstrom [1979] and Grossman-Hart [1983].

4/ In fact earlier restrictions on fees and more generally on Multi Year Procurement have been removed by the 1982 Defense Authorization Act.

5/ If $\underline{e} = 0$, the same analysis holds through, but S will never be chosen.

6/ Assume for example that v_1 is drawn from a normal distribution with mean v (the true value) and variance σ_0^2; and that at each period $t \geq 2$, the sponsor observes $u_t \sim N(v, \sigma^2)$. Then

$$v_t = \frac{v_1/\sigma_0^2 + u_2/\sigma^2 + \ldots + u_t/\sigma^2}{1/\sigma_0^2 + \ldots + 1/\sigma^2} \quad \text{and} \quad \frac{\partial V_{t+1}}{\partial v_t} = \frac{1/\sigma_0^2 + t/\sigma^2}{1/\sigma_0^2 + (t+1)/\sigma^2} < 1 \quad .$$

7/ See Baron-Myerson [1982], Guesnerie-Laffont [1982], Sappington [1982] in a static context; Freixas-Guesnerie-Tirole [1982] in a dynamic context without commitment of the sponsor, Baron-Besanko [1983a] in a dynamic context with commitment.

8/ On the other hand the firm may have a better idea about the technical possibilities of the system it is developing. But as long as the previous arguments hold, the firm still has incomplete information about the value of the project for the sponsor.

9/ It has some information about it when the contract is signed as government agencies then check the firm's capacities. This information may well deteriorate over time.

10/ Also, according to Scherer, hoarding engineers, technicians, skilled production workers and administrative personnel not required on current contracts is useful for winning and executing future contracts.

11/ I use the same notation for strategies and actions as there is no possible confusion.

12/ The sponsor assumes that the firm invested $e^{*}_{t-1}(\hat{v}_{t-1},\hat{c}_{t-1})$ last period. This belief is justified below.

13/ The initial contract may still serve as a status-quo point in the subsequent negotiation.

14/ $\bar{\Phi}_2(c_2)$ in general also depends on the government's beliefs about e_1 (i.e., on the equilibrium $\bar{e}_1$). As investment is not observed by the government, the firm has no way to influence these beliefs, and therefore I omit the argument e_1 in the function $\bar{\Phi}_2$. When investment is observed (see below), it becomes important to explicitly reintroduce this dependence.

15/ For example, when bargaining consists of a sequence of offers and counteroffers and the cost of bargaining is discounting, a party will never accept an offer that gives it a negative surplus. Nor will it in general make an offer that gives it a negative surplus and that is accepted with some probability.

16/ Assume that the sponsor makes a take-it-or-leave-it offer in the second period. The sponsor has known value v_2.The firm may have one of two costs $\underline{c}_2$ or $\bar{c}_2$ with $\underline{c}_2 < \bar{c}_2 < v_2$. There are two investment technologies. The cheap one does not involve any first-period expense and leads to cost $\bar{c}_2$. The expensive one costs $e_1 > 0$, and leads to cost $\underline{c}_2$ with probability α, and to cost $\bar{c}_2$ with probability $(1 - \alpha)$. Let us assume that

a). $\quad v_2 - \bar{c}_2 \leq \alpha\,(v_2 - \underline{c}_2)$

b). $\quad r_2 - \bar{c}_2 \geq \alpha\,(v_2 - \underline{c}_2) - e_1$

a) say that, if the sponsor knows that the firm has chosen the expensive technology, he plays "tough" (offers $\underline{c}_2$). b) then implies that, under investment observability, the optimal level of investment is $\bar{\bar{e}}_1 = 0$ (cheap technology).

Next assume that

c). $\quad \alpha\,(\bar{c}_2 - \underline{c}_2) > e_1$

and define x and y by

$$v_2 - \bar{c}_2 = \alpha x(v_2 - \underline{c}_2)$$

$$\alpha y(\bar{c}_2 - \underline{c}_2) = e_1$$

x and y belong to (0,1) from a) and c). Assume now that investment is not observable by the sponsor. The following is then a mixed strategy equilibrium: the firm chooses the expensive technology ($\bar{e}_1 = e_1$) with probability x, and the cheap one ($\bar{e}_1 = 0$) with probability $(1 - x)$. The sponsor charges $\bar{c}_2$ with probability y, and $\underline{c}_2$ with probability $(1-y)$.

Lastly to check that conditions a), b) and c) are not inconsistent, take $\{v_2 = 4; \bar{c}_2 = 3; \underline{c}_2 = 1; \alpha = 1/2; e_1 = .75\}$.

17/ For example $\{\underline{c}_2 = 1; \bar{c}_2 = 2; \underline{v}_2 = 3; \bar{v}_2 = 4.5\}$.

18/ Here I consider only self-inflicted penalties. There is a large law and economics literature on legal remedies in the event of a breach of a contract (see, e.g., Shavell [1984]). Some legal measures for damage--like the reliance measure--require more information than is assumed here. The expectation measure resembles a cancellation fee when the court has the same information ex-post as the two parties had ex-ante when they signed the contract.

19/ Let F (resp. f) be the cumulative distribution (resp. density) of the firm's cost conditional on the firm making its first period <u>equilibrium</u> investment e_1. The sponsor chooses $q = p - K$ so as to maximize $\{(1 - F(q))(-K) + F(q)(v_2 - q - K)\}$. The optimal $q^*(v_2,K)$ does not depend on K. Neither does it depend on the firm's actual investment, which is private information. Second the firm's equilibrium investment is given by:

$$- U_1'(-e_1) - \gamma \int_{\{q^*(v_2) > c_2\}} U_2'(q^*(v_2) + K - c_2) \frac{\partial \tilde{C}_2}{\partial e_1} = 0 \quad .$$

Differentiating and using the second-order condition gives $\frac{\partial e_1}{\partial K} < 0$ (the differentiation must now take into account the effect of e_1 on q^*). To obtain e_1, one must solve a fixed point problem: e_1

determines F, that determines the q^* function, which in turn affects e_1.

20/ This point is made in a somewhat different context by Williamson who notices that "a king who is known to cherish two daughters equally and is asked for screening purposes to post a hostage is better advised to offer the ugly one" ([1983], p. 527).

21/ The interaction between the possibility of bankruptcy, outside lending and the project is a topic worth studying.

References

Arrow, K. J. [1979], "The Property Rights Doctrine and Demand Revelation under Incomplete Information," in Economics and Human Welfare, Academic Press.

d'Aspremont, C. and L. A. Gerard-Varet [1979], "Incentives and Incomplete Information," Journal of Public Economics, 25-45.

Baron, D. and R. Myerson [1982], "Regulating a Monopolist with Unknown Costs," Econometrica, 911-930.

Baron, D. and D. Besanko [1983a] "A Theory of Regulation and Information in a Continuing Relationship," Mimeo.

Baron, D. and D. Besanko [1983b], "Regulation, Asymmetric Information, and Auditing," DP, Stanford Graduate School of Business.

Chatterjee, K. and W. Samuelson [1983], "Bargaining under Incomplete Information," Operations Research, 835-851.

Cramton, P. [1983], "Bargaining with Incomplete Information: An Infinite Horizon Model with Continuous Uncertainty," RP 680, Stanford Graduate School of Business.

Cramton, P. [1984], "Sequential Bargaining Mechanisms," forthcoming in Game Theoretic Models of Bargaining, ed. by A. Roth, Cambridge University Press.

Crawford, V. and J. Sobel [1982], "Strategic Information Transmission," Econometrica, 1431-1452.

Crawford, V. [1983a], "Efficient and Durable Decision Rules: A Reformulation," DP 83-19, University of California at San Diego.

Crawford, V. [1983b], "Dynamic Bargaining: Long Term Relationships Governed by Short-Term Contracts," DP 83-13, University of California at San Diego.

Freixas, X., R. Guesnerie, and J. Tirole [1982], "Planning under Incomplete Information and the Ratchet Effect," forthcoming, Review of Economic Studies.

Fudenberg, D. and J. Tirole [1983], "Sequential Bargaining with Incomplete Information," Review of Economic Studies, 221-247.

Fudenberg, D., D. Levine, and J. Tirole [1984], "Infinite-Horizon Models of Bargaining with One-Sided Incomplete Information," forthcoming in Game Theoretic Models of Bargaining, ed. by A. Roth, Cambridge University Press.

Green, J. and N. Stokey [1980], "A Two Person Game of Information Transmission," HIER DP 751.

Grout, P. [1984], "Investment and Wages in the Absence of Binding Contracts: A Nash Bargaining Approach", Econometrica, 449-460.

Grossman, S. and O. Hart [1983], "An Analysis of the Principal-Agent Problem," Econometrica, 7-46.

Guesnerie, R. and J. J. Laffont [1982], "Control of Public Firms under Incomplete Information," CERAS.

Holmstrom, B. [1979], "Moral Hazard and Observability," Bell Journal of Economics, 74-91.

Holmstrom, B. [1983], "Equilibrium Long-Term Labor Contracts," Quarterly Journal of Economics, Supplement, 23-54.

Klein, B., R. Crawford, and A. Alchian [1978], "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," Journal of Law and Economics, 297-326.

Kreps, D. and R. Wilson [1982], "Sequential Equilibria," Econometrica, 863-894.

Laffont, J. J. and J. Tirole [1984], "Using Cost Observation to Regulate a Public Firm," Mimeo.

Marschak, T. and J. Yahav [1966], "The Sequential Selection of Approaches to a Task," Management Science, 627-647.

Mirrless, J. [1975], "The Theory of Moral Hazard and Unobservable Behavior - Part I," Nuffield College, Mimeo.

Myerson, R. [1983], "Mechanisms Designed by an Informed Principal," Econometrica, 1767-1797.

Myerson, R. and M. Satterthwaite [1983], "Efficient Mechanisms for Bilateral Trading," Journal of Economic Theory, 265-281.

Moore, J. [1983], "Labor Contracts with Two-Sided Private Information," London School of Economics.

Peck, M. and F. Scherer [1962], The Weapons Acquisition Process: An Economic Analysis, Graduate School of Business Administration, Harvard University.

Pratt,J. and R. Zeckhauser [1982] "Incentive Based Decentralization: Expected Externality Payments Induce Efficient Behavior in Groups," forthcoming in G. Feiwel, Ed. Kenneth Arrow and Economic Theory London-McMillan 1985.

Ross, S. [1973], "The Economic Theory of Agency: The Principal's Problem," American Economic Review, 134-139.

Rubinstein, A. [1983], "A Bargaining Model with Incomplete Information," Mimeo.

Sappington, D. [1982], "Optimal Regulation of Research and Development under Imperfect Information," Bell Journal of Economics, 354-368.

Scherer, F. [1964], The Weapons Acquisition Process: Economic Incentives, Graduate School of Business Administration, Harvard University.

Shavell, S. [1979], "Risk Sharing and Incentives in the Principal and Agent Relationship," Bell Journal of Economics, 55-73.

Shavell, S. [1984], "The Design of Contracts and Remedies for Breach," Quarterly Journal of Economics, 121-148.

Sobel, J. and I. Takahashi [1983], "A Multi-Stage Model of Bargaining," Review of Economic Studies, 411-426.

Thaler, D. and K. Ugoff [1982], "The Economics of Multiyear Contracting," RP 345, Center for Naval Analysis.

Weitzman, M. [1979], "Optimal Search for the Best Alternative," Econometrica, 641-654.

Weitzman, M. and K. Roberts [1981], "Funding Criteria for Research, Development and Exploration Projects," Econometrica, 1261-1288.

Williamson, O. [1967], "The Economics of Defense Contracting: Incentives and Performance," in Issues in Defense Economics, ed. by MacLean, Columbia University Press.

Williamson, O. [1975], Markets and Hierarchies: Analysis and Antitrust Implications, New York, Free Press.

Williamson, O. [1983], "Credible Commitments: Using Hostages to Support Exchange," American Economic Review, 519-540.

REPORTS IN THIS SERIES

160. "The Structure and Stability of Competitive Dynamical Systems," by David Cass and Karl Shell.
161. "Monopolistic Competition and the Capital Market," by J. E. Stiglitz.
162. "The Corporation Tax," by J. E. Stiglitz.
163. "Measuring Returns to Scale in the Aggregate and the Scale Effect of Public Goods," by David A. Starrett.
164. "Monopoly, Quality, and Regulation," by Michael Spence.
165. "A Note on the Budget Constraint in a Model of Borrowing," by Duncan K. Foley and Martin F. Hellwig.
166. "Incentitives, Risk, and Information: Notes Towards a Theory of Hierarchy," by Joseph E. Stiglitz.
167. "Asymptotic Expansions of the Distributions of Estimates in Simultaneous Equations for Alternative Parameter Sequences," by T. W. Anderson.
168. "Estimation of Linear Functional Relationships: Approximate Distributions and Connections with Simultaneous Equations in Econometrics," by T. W. Anderson.
169. "Monopoly and the Rate of Extraction of Exhaustible Resources," by Joseph E. Stiglitiz.
170. "Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information," by Michael Rothschild and Joseph Stiglitz.
171. "Strong Consistency of Least Squares Estimates in Normal Linear Regression," by T. W. Anderson and John B. Taylor.
172. "Incentive Schemes under Differential Information Structures: An Application to Trade Policy," by Partha Dasgupta and Joseph Stiglitz.
173. "The Incidence and Efficiency Effects of Taxes on Income from Capital," by John B. Shoven.
174. "Distribution of a Maximum Likelihood Estimate of a Slope Coefficient: The LIML Estimate for Known Covariance Matrix," by T. W. Anderson and Takamitsu Sawa.
175. "A Comment on the Test of Overidentifying Restrictions," by Joseph B. Kadane and T. W. Anderson.
176. "An Asymptotic Expansion of the Distribution of the Maximum Likelihood Estimate of the Slope Coefficient in a Linear Functional Relationship," by T. W. Anderson.
177. "Some Experimental Results on the Statistical Properties of Least Squares Estimates in Control Problems," by T. W. Anderson and John B. Taylor.
178. "A Note on "Fulfilled Expectations" Equilibria," by David M. Kreps.
179. "Uncertainty and the Rate of Extraction under Alternative Institutional Arrangements," by Partha Dasgupta and Joseph E. Stiglitz.
180. "Budget Displacement Effects of Inflationary Finance," by Jerry Green and E. Sheshinski.
181. "Towards a Marxist Theory of Money," by Duncan K. Foley.
182. "The Existence of Futures Markets, Noisy Rational Expectations and Informational Externalities," by Sanford Grossman.
183. "On the Efficiency of Competitive Stock Markets where Traders have Diverse Information," by Sanford Grossman.
184. "A Bidding Model of Perfect Competition," by Robert Wilson.
185. "A Bayesian Approach to the Production of Information and Learning by Doing," by Sanford J. Grossman, Richard E. Kihlstrom and Leonard J. Mirman.
186. "Disequilibrium Allocations and Recontracting," by Jean-Michel Grandmont, Guy Laroque and Yves Younes.
187. "Agreeing to Disagree," by Robert J. Aumann.
188. "The Maximum Likelihood and the Nonlinear Three Stage Least Squares Estimator in the General Nonlinear Simultaneous Equation Model," by Takeshi Amemiya.
189. "The Modified Second Round Estimator in the General Qualitative Response Model," by Takeshi Amemiya.
190. "Some Theorems in the Linear Probability Model," by Takeshi Amemiya.
191. "The Bilinear Complementarity Problem and Competitive Equilibria of Linear Economic Models," by Robert Wilson.
192. "Noncooperative Equilibrium Concepts for Oligopoly Theory," by L. A. Gerard-Varet.
193. "Inflation and Costs of Price Adjustment," by Eytan Sheshinski and Yoram Weiss.
194. "Power and Taxes in a Multi-Commodity Economy," by R. J. Aumann and M. Kurz.
195. "Distortion of Preferences, Income Distirbution and the Case for a Linear Income Tax," by Mordecai Kurz.
196. "Search Strategies for Nonrenewable Resource Deposits," by Richard J. Gilbert.
197. "Demand for Fixed Factors, Inflation and Adjustment Costs," by Eytan Sheshinski and Yoram Weiss.
198. "Bargains and Ripoffs: A Model of Monopolistically Competitive Price Dispersions," by Steve Salop and Joseph Stiglitz.
199. "The Design of Tax Structure: Direct Versus Indirect Taxation by A. B. Atkinson and J. E. Stiglitz.
200. "Market Allocations of Location Choice in a Model with Free Mobility," by David Starrett.
201. "Efficiency in the Optimum Supply of Public Goods," by Lawrence J. Lau, Eytan Sheshinski and Joseph E. Stiglitz.
202. "Risk Sharing, Sharecropping and Uncertain Labor Markets," by David M. G. Newberry.
203. "On Non-Walrasian Equilibria," by Frank Hahn.
204. "A Note on Elasticity of Substitution Functions," by Lawrence J. Lau.
205. "Quantity Constraints as Substitutes for Inoperative Markets: The Case of the Credit Markets," by Mordecai Kurz.
206. "Incremental Consumer's Surplus and Hedonic Price Adjustment," by Robert D. Willig.
207. "Optimal Depletion of an Uncertain Stock," by Richard Gilbert.
208. "Some Minimum Chi-Square Estimators and Comparisons of Normal and LogisticaModels in Qualitative Response Analysis," by Kumio Morimune.
209. "A Characterization of the Optimality of Equilibrium in Incomplete Markets," by Sanford J. Grossman.
210. "Inflation and Taxes in a Growing Economy with Debt and Equity Finance," by M. Feldstein, J. Green and E. Sheshinski.
211. "The Specification and Estimation of a Multivariate Logit Model," by Takeshi Amemiya.
212. Prices and Queues as Screening Devices in Competitive Markets," by Joseph E. Stiglitz.
213. "Conditions for Strong Consistency of Least Squares Estimates in Linear Models," by T. W. Anderson and John B. Taylor.
214. "Utilitarianism and Horizontal Equity: The Case for Random Taxation," by Joseph E. Stiglitz.
215. "Simple Formulae for Optimal Income Taxation and the Measurement of Inequality," by Joseph E. Stiglitz.
216. "Temporal Resolution of Uncertainty and Dynamic Choice Behavior," by David M. Kreps and Evan L. Porteus.
217. "The Estimation of Nonlinear Labor Supply Functions with Taxes from a Truncated Sample," by Michael Hurd.
218. "The Welfare Implications of the Unemployment Rate," by Michael Hurd.
219. "Keynesian Economics and General Equilibrium Theory: Reflections on Some Current Debates," by Frank Hahn.
220. "The Core of an Exchange Economy with Differential Information," by Robert Wilson.
221. "A Competitive Model of Exchange," by Robert Wilson.
222. "Intermediate Preferences and the Majority Rule," by Jean-Michel Grandmont.
223. "The Fixed Price Equilibria: Some Results in Local Comparative Statics," by Guy Laroque.
224. "On Stockholder Unanimity in Making Production and Financial Decisions," by Sanford J. Grossman and Joseph E. Stiglitz.
225. "Selection of Regressors," by Takeshi Amemiya.
226. "A Note on A Random Coefficients Model," by Takeshi Amemiya.
227. "A Note on a Heteroscedastic Model," by Takeshi Amemiya.
228. "Welfare Measurement for Local Public Finance," by David Starrett.
229. "Unemployment Equilibrium with Rational Expectations," by W. P. Heller and R. M. Starr.
230. "A Theory of Competitive Equilibrium in Stock Market Economies," by Sanford J. Grossman and Oliver D. Hart.
231. "An Application of Stein's Methods to the Problem of Single Period Control of Regression Models," by Asad Zaman.
232. "Second Best Welfare Economics in the Mixed Economy," by David Starrett.
233. "The Logic of the Fix-Price Method," by Jean-Michel Grandmont.
234. "Tables of the Distribution of the Maximum Likelihood Estimate of the Slope Coefficient and Approximations," by T. W. Anderson and Takamitsu Sawa.
235. "Further Results on the Informational Efficiency of Competitive Stock Markets," by Sanford Grossman.
236. "The Estimation of a Simultaneous-Equation Tobit Model," by Takeshi Amemiya.
237. "The Estimation of a Simultaneous-Equation Generalized Probit Model," by Takeshi Amemiya.
238. "The Consistency of the Maximum Likelihood Estimator in a Disequilibrium Model," by T. Amemiya and G. Sen.
239. "Numerical Evaluation of the Exact and Approximate Distribution Functions of the Two-Stage Least Squares Estimate," by T. W. Anderson and Takamitsu Sawa.
240. "Risk Measurement of Public Projects," by Robert Wilson.
241. "On the Capitalization Hypothesis in Closed Communities," by David Starrett.
242. "A Note on the Uniqueness of the Representation of Commodity-Augmenting Technical Change," by Lawrence J. Lau.
243. "The Property Rights Doctrine and Demand Revelation under Incomplete Information," by Kenneth J. Arrow.
244. "Optimal Capital Gains Taxation Under Limited Information," by Jerry R. Green and Eytan Sheshinski.
245. "Straightforward Individual Incentive Compatibility in Large Economies," by Peter J. Hammond.
246. "On the Rate of Convergence of the Core," by Robert J. Aumann.
247. "Unsatisfactory Equilibria," by Frank Hahn.
248. "Existence Conditions for Aggregate Demand Functions: The Case of a Single Index," by Lawrence J. Lau.
249. "Existence Conditions for Aggregate Demand Functions: The Case of Multiple Indexes," by Lawrence J. Lau.
250. "A Note on Exact Index Numbers," by Lawrence J. Lau.
251. "Linear Regression Using Both Temporally Aggregated and Temporally Disaggregated Data," by Cheng Hsiao.
252. "The Existence of Economic Equilibria: Continuity and Mixed Strategies," by Partha Dasgupta and Eric Maskin.
253. "A Complete Class Theorem for the Control Problem and Further Results on Admissibility and Inadmissibility," by Asad Zaman.
254. "Measure-Based Values of Market Games," by Sergiu Hart.
255. "Altruism as an Outcome of Social Interaction," by Mordecai Kurz.
256. "A Representation Theorem for 'Preference for Flexibility'," by David M. Kreps.
257. "The Existence of Efficient and Incentive Compatible Equilibria with Public Goods," by Theodore Groves and John O. Ledyard.
258. "Efficient Collective Choice with Compensation," by Theodore Groves.
259. "On the Impossibility of Informationally Efficient Markets," by Sanford J. Grossman and Joseph E. Stiglitz.

REPORTS IN THIS SERIES

260. "Values for Games Without Sidepayments: Some Difficulties With Current Concepts," by Alvin E. Roth.
261. "Martingles and the Valuation of Redundant Assets," by J. Michael Harrison and David M. Kreps.
262. "Autoregressive Modelling and Money – Income Causality Detection," by Cheng Hsiao.
263. "Measurement Error in a Dynamic Simultaneous Equations Model without Stationary Disturbances," by Cheng Hsiao.
264. "The Measurement of Deadweight Loss Revisited," by W. E. Diewert.
265. "The Elasticity of Derived Net Supply and a Generalized Le Chatelier Principle," by W. E. Diewert.
266. "Income Distribution and Distortion of Preferences: the ℓ Commodity Case," by Mordecai Kurz.
267. "The n^{-2}–Order Mean Squared Errors of the Maximum Likelihood and the Minimum Logit Chi-Square Estimator," by Takeshi Amemiya.
268. "Temporal Von Neumann-Morgenstern and Induced Preferences," by David M. Kreps and Evan L. Porteus.
269. "Take-Over Bids and the Theory of the Corporation," by Stanford Grossman and Oliver D. Hart.
270. "The Numerical Values of Some Key Parameters in Econometric Models," by T. W. Anderson, Kimio Morimune and Takamitsu Sawa.
271. "Two Representations of Information Structures and their Comparisons," by Jerry Green and Nancy Stokey.
272. "Asymptotic Expansions of the Distributions of Estimators in a Linear Functional Relationship when the Sample Size is Large," by Naoto Kunitomo.
273. "Public Goods and Power," by R. J. Aumann, M. Kurz and A. Neyman.
274. "An Axiomatic Approach to the Efficiency of Non-Cooperative Equilibrium in Economies with a Continuum of Traders," by A. Mas-Colell.
275. "Tables of the Exact Distribution Function of the Limited Information Maximum Likelihood Estimator when the Covariance Matrix in Known," by T. W. Anderson and Takamitsu Sawa.
276. "Autoregressive Modeling of Canadian Money and Income Data," by Cheng Hsiao.
277. "We Can't Disagree Forever," by John D. Geanakoplos and Heraklis Polemarchakis.
278. "Constrained Excess Demand Functions," by Herklis M. Polemarchakis.
279. "On the Bayesian Selection of Nash Equilibrium," by Akira Tomioka.
280. "Disequilibrium Econometrics in Simultaneous Equations Systems," by C. Gourierous, J. J. Laffont and A. Monfort.
281. "Duality Approaches to Microeconomic Theory," by W. E. Diewert.
282. "A Time Series Analysis of the Impact of Canadian Wage and Price Controls," by Cheng Hsiao and Oluwatayo Fakiyesi.
283. "A Strategic Theory of Inflation," by Mordecai Kurz.
284. "A Characterization of Vector Measure Games in pNA," by Yair Tauman.
285. "On the Method of Taxation and the Provision of Local Public Goods," by David A. Starrett.
286. "An Optimization Problem Arising in Economics: Approximate Solutions, Linearity, and a Law of Large Numbers," by Sergiu Hart.
287. "Asymptotic Expansions of the Distributions of the Estimates of Coefficients in a Simultaneous Equation System," by Yasunori Fujikoshi, Kimio Morimune, Naoto Kunitomo and Masanobu Taniguchi.
288. "Optimal & Voluntary Income Distribution," by K. J. Arrow.
289. "Asymptotic Values of Mixed Games," by Abraham Neyman.
290. "Time Series Modelling and Causal Ordering of Canadian Money, Income and Interest Rate," by Cheng Hsiao.
291. "An Analysis of Power in Exchange Economies," by Martin J. Osborne.
292. "Estimation of the Reciprocal of a Normal Mean," by Asad Zaman.
293. "Improving the Maximum Likelihood Estimate in Linear Functional Relationships for Alternative Parameter Sequences," by Kimio Morimune and Naoto Kunitomo.
294. "Calculation of Bivariate Normal Integrals by the Use of Incomplete Negative-Order Moments," by Kei Takeuchi and Akimichi Takemura.
295. "On Partitioning of a Sample with Binary-Type Questions in Lieu of Collecting Observations," by Kenneth J. Arrow, Leon Pesotchinsky and Milton Sobel.
296.
297. "The Two Stage Least Absolute Deviations Estimators," by Takeshi Amemiya.
298. "Three Essays on Capital Markets," by David M. Kreps.
299. "Infinite Horizon Programs," by Michael J. P. Magill.
300. "Electoral Outcomes and Social Log-Likelihood Maxima," by Peter Coughlin and Shmuel Nitzan.
301. "Notes on Social Choice and Voting," by Peter Coughlin.
302. "Overlapping Expectations and Hart's Conditions for Equilibrium in a Securities Model," by Peter J. Hammond.
303. "Directional and Local Electorate Competitions with Probabilistic Voting," by Peter Coughlin and Shmuel Nitzan.
304. "Asymptotic Expansions of the Distributions of the Test Statistics for Overidentifying Restrictions in a System of Simultaneous Equations," by Kunitomo, Morimune, and Tsukuda.
305. "Incomplete Markets and the Observability of Risk Preference Properties," by H. H. Polemarchakis and L. Selden.
306. "Multiperiod Securities and the Efficient Allocation of Risk: A Comment on the Black-Scholes Option Pricing Model," by David M. Kreps.
307. "Asymptotic Expansions of the Distributions of k-Class Estimators when the Disturbances are Small," by Naoto Kunitomo, Kimio Morimune, and Yoshihiko Tsukuda.
308. "Arbitrage and Equilibrium in Economies with Infinitely Many Commodities," by David M. Kreps.
309. "Unemployment Equilibrium in an Economy with Linked Prices," by Mordecai Kurz.
310. "Pareto Optimal Nash Equilibria are Competitive in a Repeated Economy," by Mordecai Kurz and Sergiu Hart.
311. "Identification," by Cheng Hsiao.
312. "An Introduction to Two-Person Zero Sum Repeated Games with Incomplete Information," by Sylvain Sorin.
313. "Estimation of Dynamic Models with Error Components," by T. W. Anderson and Cheng Hsiao.
314. "On Robust Estimation in Certainty Equivalence Control," by Anders H. Westlund and Hans Stenlund.
315. "On Industry Equilibrium Under Uncertainty," by J. Dreze and E. Sheshinski.
316. "Cost Benefit Analysis and Project Evaluation from the Viewpoint of Productive Efficiency," by W. E. Diewert.
317. "On the Chain-Store Paradox and Predation: Reputation for Toughness," by D. M. Kreps and Robert Wilson.
318. "On the Number of Commodities Required to Represent a Market Games," Sergiu Hart.
319. "Evaluation of the Distribution Function of the Limited Information Maximum Likelihood Estimator," by T. W. Anderson, Naoto Kunitomo, and Takamitsu Sawa.
320. "A Comparison of the Logit Model and Normal Discriminant Analysis when the Independent Variables are Binary," by Takeshi Amemiya and James L. Powell.
321. "Efficiency of Resource Allocation by Uninformed Demand," by Theodore Groves and Sergiu Hart.
322. "A Comparison of the Box-Cox Maximum Likelihood Estimator and the Nonlinear Two Stage Least Squares Estimator," by Takeshi Amemiya and James L. Powell.
323. "Comparison of the Densities of the TSLS and LIMLK Estimators for Simultaneous Equations," by T. W. Anderson, Naoto Kunitomo, and Takamitsu Sawa.
324. "Admissibility of the Bayes Procedure Corresponding to the Uniform Prior Distribution for the Control Problem in Four Dimensions but Not in Five," by Charles Stein and Asad Zaman.
325. "Some Recent Developments on the Distributions of Single-Equation Estimators," by T. W. Anderson.
326. On Inflation," by Frank Hahn.
327. Two Papers on Majority Rule: "Continuity Properties of Majority Rule with Intermediate Preferences," by Peter Coughlin and Kuan-Pin Lin; and, "Electroal Outcomes with Probabilistic Voting and Nash Social Welfare Maxima," by Peter Coughlin and Shmuel Nitzan.
328. "On the Endogenous Formation of Coalitions," by Sergiu Hart and Mordecai Kurz.
329. "Controllability, Pecuniary Externalities and Optimal Taxation," by David Starrett.
330. "Nonlinear Regression Models," by Takeshi Amemiya.
331. "Paradoxical Results from Inada's Conditions for Majority Rule," by Herve Raynaud.
332. "On Welfare Economics with Incomplete Information and the Social Value of Public Information," by Peter J. Hammond.
333. "Equilibrium Policy Proposals with Abstentions," by Peter J. Coughlin.
334. "Infinite Excessive and Invariant Measures," by Michael I. Taksar.
335. "The Life-Cycle Hypothesis and the Effects of Social Security and Private Pensions on Family Savings," by Mordecai Kurz.
336. "Optimal Retirement Age," by Mordecai Kurz.
337. "Bayesian Incentive Compatible Beliefs," by Claude d'Aspremont and Louis-Andre Gerard-Varet.
338. "Qualitative Response Models: A Survey," by Takeshi Amemiya.
339. "The Social Costs of Monopoly and Regulation: A Game Theoretic Analysis," by William P. Rogerson.
340. "Sequential Equilibria," by David M. Kreps and Robert Wilson.
341. "Enhancing of Semigroups," by Michael I. Taksar.
342. "Formulation and Estimation of Dynamic Models Using Panel Data," by T. W. Anderson and Cheng Hsiao.
343. "Ex-Post Optimality as a Dynamically Consistent Objective for Collective Choice Under Undertainty," by Peter Hammond.
344. "Three Lectures in Monetary Theory," by Frank H. Hahn.
345. "Socially Optimal Investment Rules in the Presence of Incomplete Markets and Other Second Best Distortions," by Frank Milne and David A. Starrett.
346. "Approximate Purification of Mixed Strategies," by Robert Aumann, Yitzhak Katznelson, Roy Radner, Robert W. Rosenthal, and Benjamin Weiss.
347. "Conditions for Transistivity of Majority Rule with Algorithmic Interpretations," by Herve Raynaud.
348. "How Restrictive Actually are the Value Restriction Conditions," by Herve Raynaud.
349. "Cournot Duopoly in the Style of Fulfilled Expectations Equilibrium, " by William Novshek and Hugh Sonnenschein.
350. "Law of Large Numbers for Random Sets and Allocation Processes," by Zvi Artstein and Sergiu Hart.
351. "Risk Perception in Psychology and Economics," by Kenneth J. Arrow.
352. "Shrunken Predictors for Autoregressive Models," by Taku Yamamoto.
353. "Predation, Reputation, and Entry Deterrence," by Paul Milgrom and John Roberts.
354. "Social and Private Production Objectives in the Sequence Economy," by David Starrett
355. "Recursive Rational Choice," by Alain Lewis.
356. "Least Absolute Deviations Estimation for Censored and Truncated Regression Models," by James Powell.
357. "Relatively Recursive Rational Choice," by Alain Lewis.
358. "A Theory of Auctions and Competitive Bidding," by Paul Milgrom and Robert Weber.
359. "Facing an Uncertain Future," by W. M. Gorman.
360. "The Individual Freedom Allowed by the Value Restriction Condition," by Herve Raynaud.
361. "Incomplete Resource Allocation Mechanisms," by P. J. Hammond.
362. "The Comparative Dynamics of Efficient Programs of Capital Accumulation and Resource Depletion," by W. E. Diewert and T. R. Lewis.
363. "Optimum Pricing Policy Under Stochastic Inflation," by E. Sheshinski and Y. Weiss.
364. "Capital Accumulation and the Characteristics of Private Intergenerational Transfers," by M. Kurz.
365. "Asymptotic Efficiency and Higher Order Efficiency of the Limited Information Maximum Likelihood Estimator in Large Econometric Models," by N. Kunitomo.
366. "Semi-Values of Political Economic Games," by A. Neyman.
367. "Non-Zero-Sum Two-Person Repeated Games with Incomplete Information," by S. Hart.
368. "Partially Generalized Least Squares and Two-Stage Least Squares and Two-Stage Least Squares Estimators," by T. Amemiya.
369. "Lipschitz Properties of Solution in Mathematical Programming," by B. Cornet and G. Laroque.
370. "Multiple Hypothesis Testing," by N. E. Savin.
371. "Team Theory and Decentralized Resource Allocation: An Example," by K. J. Arrow.
372. "Testing for Unit Roots: 2," by G. B. A. and Evans and N. E. Savin.
373. "Asymptotic Bias of the Least Squares Estimator for Multivariate Autoregressive Models," by T. Yamamoto and N. Kunitomo.
374. "The Asymptotic Normality of Two-Stage Least Absolute Deviations Estimators," by J. Powell.
375. "Rational Cooperation in the Finitely-Repeated Prisoner's Dilemma," by D. Kreps, P. Milgrom, J. Roberts, and R. Wilson.

376. "Necessary and Sufficient Conditions for Single-Peakedness Along a Linearly Ordered Set of Policy Alternatives" by P. J. Coughlin and M. J. Hinich.

377. "The Role of Reputation in a Regeated Agency Problem Involving Information Transmission" by W. P. Rogerson.

378. "Unemployment Equilibrium with Stochastic Rationing of Supplies" by Ho-mou Wu.

379. "Optimal Price and Income Regulation Under Uncertainty in the Model with One Producer" by M. I. Taksar.

380. "On the NTU Value" by Robert J. Aumann.

381. "Best Invariant Estimation of a Direction Parameter with Application to Linear Functional Relationships and Factor Analysis" by T. W. Anderson, C. Stein and A. Zaman.

382. "Informational Equilibrium" by Robert Kast.

383. "Cooperative Oligopoly Equilibrium" by Mordecai Kurz.

384. "Reputation and Product Quality" by William P. Rogerson.

385. "Auditing: Perspectives from Multiperson Decision Theory" by Robert Wilson.

386. "Capacity Pricing" by Oren, Smith and Wilson.

387. "Consequentialism and Rationality in Dynamic Choice Under Uncertainty" by P. J. Hammond.

388. "The Structure of Wage Contracts in Repeated Agency Models" by W. P. Rogerson.

389. "1982 Abraham Wald Memorial Lectures, Estimating Linear Statistical Relationships" by T. W. Anderson.

390. "Aggregates, Activities and Overheads" by W. M. Gorman.

391. "Double Auctions" by Robert Wilson.

392. "Efficiency and Fairness in the Design of Bilateral Contracts" by S. Honkapohja.

393. "Diagonality of Cost Allocation Prices" by L. J. Mirman and A. Neyman.

394. "General Asset Markets, Private Capital Formation, and the Existence of Temporary Walrasian Equilibrium" by P. J. Hammond.

395. "Asymptotic Normality of the Censored and Truncated Least Absolute Deviations Estimators" by L. L. Powell.

396. "Dominance-Solvability and Cournot Stability" by Herve Moulin.

397. "Managerial Incentives, Investment and Aggregate Implications" by B. Holmstrom and L. Weiss.

398. "Generalizations of the Censored and Truncated Least Absolute Deviations Estimators" by J. L. Powell.

399. "Behavior Under Uncertainty and its Implications for Policy" by K.J. Arrow.

400. "Third-Order Efficiency of the Extended Maximum Likelihood Estimators in a Simultaneous Equation System" by K. Takeuchi and K. Morimune.

401. "Short-Run Analysis of Fiscal Policy in a Simple Perfect Foresight Model" by K. Judd.

402. "Estimation of Failure Rate From A Complete Record of Failures and a Partial Record of Non-Failures" by K. Suzuki.

403. "Applications of Semi-Regenerative Theory to Computations of Stationary Distributions of Markov Chains" by

404. "On the Optimality of Individual Behavior in First Come Last Served Queues with Preemption and Balking" by Refael Hassin.

405. "Entry with Exit: An Extensive Form Treatment of Predation with Fanancial Constraints" by J. P. Benoit.

406. "Search Among Queues" by A. Glazer and R. Hassin.

407. "The Space of Polynomials in Measures is Internal" by J. Reichers and Y. Tauman.

408. "Planning Under Incomplete Information and the Ratchet Effect" by X. Freixas, R. Guesnerie and J. Tirole.

409. "A Theory of Dynamic Oligopoly, I: Overview and Quantity Competition with Large Fixed Costs" by Eric Maskin and Jean Tirole.

410. "Approximate Measures of the Social Welfare Benefits of Labor Projects" by Peter Hammond.

411. "Transversality Conditions for Some Infinite Horizon Discrete Time Optimization Problems" by Ivar Ekeland and Jose A. Scheinkman.

412. "Asymptotic Efficiency of the Partial Likelihood Estimator in the Proportional Hazard Model" by Aaron K. Hahn.

413. "A Monte Carlo Comparison of Estimators for Censored Regression Models" by Harry J. Paarsch.

414. "Instrumental-Variable Estimation of an Error-Components Model" by Takeshi Amemiya and Thomas E. MaCurdy.

415. "An Axiomatization of the Non-Transferable Utility Value" by Robert J. Aumann.

416. "Diffusion Approximation in Arrow's Model of Exhaustable Resources" by Darrell Duffie and Michael Taksar.

417. "The Shapley Value in the Non Differentiable Case" by Jean François Mertens.

418. "The Minimax Theorem for U.S.C.–L.S.C. Payoff Functions" by Jean François Mertens.

419. "Altruistic Growth Economies, Part I. Existence of Bequest Equilibria Part II. Properties of Bequest Equilibria" by Debraj Ray and Douglas Bernheim.

420. "On the Existence of Cournot Equilibrium" by William Novshek.

421. "Equilibrium Turnpike Theory with Constant Returns to Scale and Possibly Heterogenous Discount Factors" by Jeffrey L. Coles.

422. "Components of Variance in Manova" by T. W. Anderson.

423. "Prices for Homogenous Cost Functions" by Leonard J. Mirman and Abraham Neyman.

424. "On the Duration of Agreements" by Milton Harris and Bengt Holmstrom.

425. "A Sequential Signalling Model of Convertible Debt Call Policy" by Milton Harris and Arthur Raviv.

426. "On the Marginal Cost of Government Spending" by David Starrett.

427. "Self-Agreed Cartel Rules" by Kevin Roberts.

428. "Dynamic Models of Oligopoly" by Drew Fudenberg and Jean Tirole.

429. "A Theory of Exit in Oligopoly" by Drew Fudenberg and Jean Tirole.

430. "Consumer Information in Markets with Random Product Quality: The Case of Queues and Balking" by Rafael Hassin.

431. "Incentive Efficiency of Double Auctions" by Robert Wilson.

432. "Efficient Trading" by Robert Wilson.

433. "The Economic Theory of Individual Behavior Toward Risk: Theory, Evidence and New Directions" by Mark J. Machina.

434. "Reputations in Games and Markets" by Robert Wilson

435. "Multilateral Incentive Compatibility in Continuum Economies" by Peter J. Hammond.

436. "The First Order Approach to Principal Agent Problems" by William P. Rogerson

437. "Maximum Rank Correlation Estimator and Generalized Median Estimator in Censored Regression and Survival Models" by Aaron K. Han.

List of Reports

438. "On Endogenous Competitive Business Cycles: by Jean-Michel Grandmont.

439. "A Complete Characterization of ARMA Solutions to Linear Rational Expectations Models" by George Evans and Seppo Honkapohja.

440. "Asset Bubbles and Overlapping Generations: A Synthesis" by Jean Tirole.

441. "Two Equivalence Theorems for the 'Finite Coalition Core' of a Continuum Economy" by Peter J. Hammond.

442. "Managerial Incentives and Non-Wage Benefits" by William Rogerson.

443. "A Survey of Agency Models of Organizations" by Daniel Levinthal.

444. "Two Papers on Sequential Bargaining: Part I. Sequential Bargaining Mechanisms. Part II. Bargaining with Incomplete Information an Infinite Horizon Model with Continuous Uncertainty" by Peter Cramton.

445. "Borrowing Constraints and Aggregate Economic Activity" by Jose A. Scheinkman and Laurence Weiss.

446. "Periodic and Aperiodic Behaviour in Discrete Onedimensional Dynamical Systems" by Jean-Michel Grandmont.

447. "Contractual Paradigms Rational Expectations and Seniority Rules in The Theory of Long-Term Labor Contracts" by James Anton.

448. "The Maximum Rank Correlation Estimator in Classical, Censored, and Discrete Regression Models" by Aaron K. Han.

449. "Consequentialist Social Norms for Public Decisions" by Peter Hammond.

450. "On Asymmetric Information, Unemployment and Inflexible Wages," by Mordecai Kurz.

451. "The Economics of Agency," by Kenneth J. Arrow.

452. "On Equilibria of Bid-Ask Markets," by Robert Wilson.

453. "Multidimensional Signaling," By Martine Quinzii & Jean-Charles Rochet

454. "Inequality, Malnutrition and Unemployment: A Critique of the Competitive Market Mechanism," by Partha Dasgupta and Debraj Ray.

455. "Procurement, Cost Overruns and Severance: A Study in Commitment and Renegotiation," by Jean Tirole.